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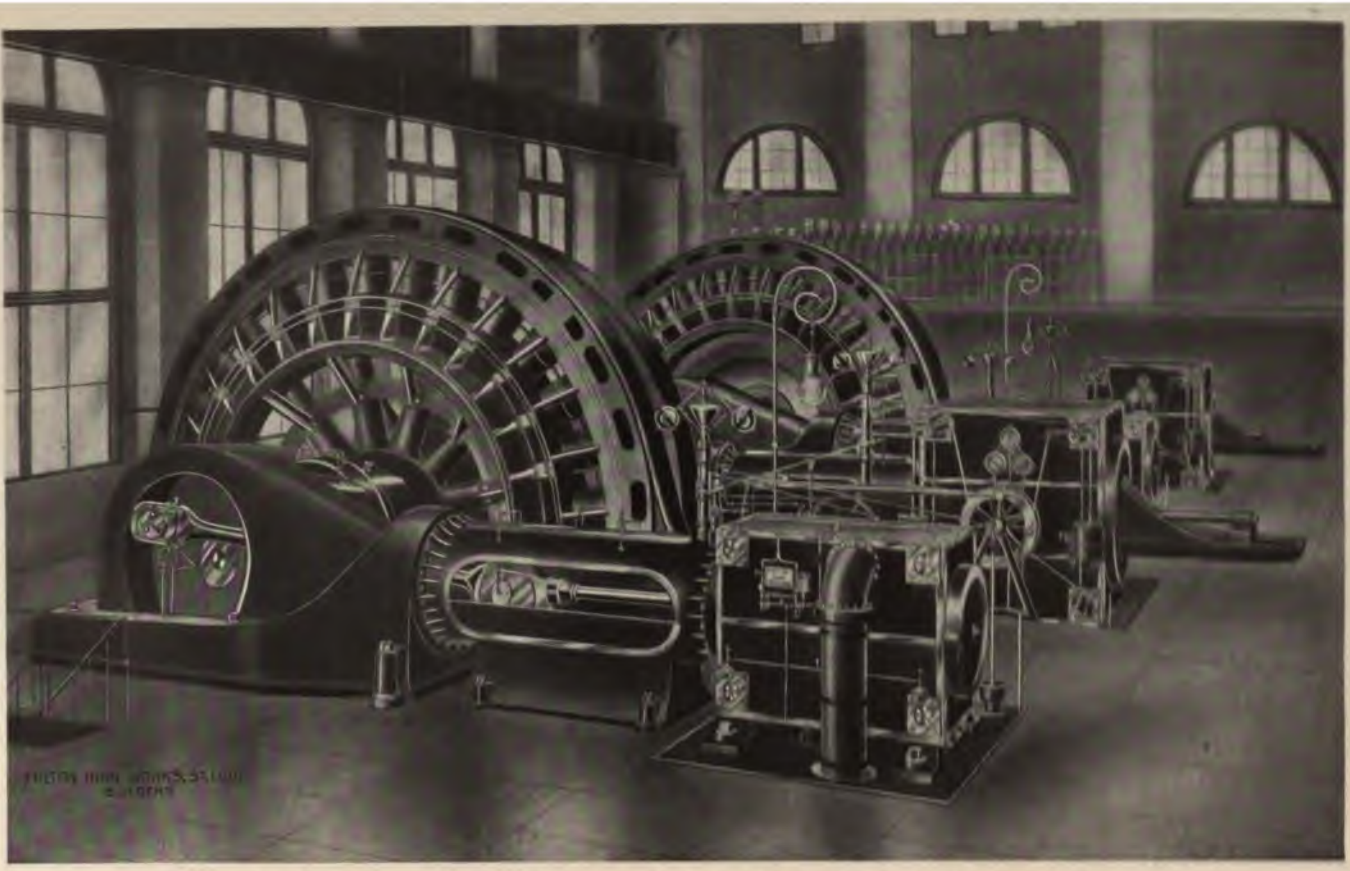

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CYCLOPEDIA

of

Applied Electricity

A Practical Guide for

ELECTRICIANS, MECHANICS, ENGINEERS, STUDENTS,
TELEGRAPH AND TELEPHONE OPERATORS,
AND ALL OTHERS INTERESTED
IN ELECTRICITY

Prepared by a Corps of

EXPERTS, ELECTRICAL ENGINEERS AND DESIGNERS

Illustrated with over Two Thousand Engravings

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AT
ARMOUR INSTITUTE OF TECHNOLOGY
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Preface

REALIZING the great need for a more scientific knowledge of electricity on the part of thousands of practical men of limited technical education, an attempt has been made in the following pages to give a presentation of the subject which shall be easily understood by such men, and at the same time, cover all the essential principles and methods. The principles usually deduced by higher mathematics are here made clear by careful explanation and a large number of diagrams drawn especially for the text. Numerous engravings exemplify modern practice, and form a pictorial index to the latest and best methods of applying electricity to lighting, railways, power transmission, machine tools, etc.

¶ The Cyclopedia of Applied Electricity is based upon the method which the American School of Correspondence has developed and successfully used for many years in teaching practical electricians the scientific principles underlying their work. It is compiled from the most valuable of the School's Instruction Papers and forms a simple, practical, concise, and convenient reference work for the shop, the library, the school, and the home.

¶ The success which the American School of Correspondence has attained in teaching thousands of electricians is in itself the best possible guarantee for the present work. Therefore, while these volumes are a marked innovation in technical literature, representing as they do the best methods of a large number of *different* authors, each an acknowledged authority in his work,—thev are by no means an experiment, but are in fact the essence successful method yet devised for the education of the busy working man.

¶ Among the sections of most practical value are those on Alternating Current Machinery, Storage Batteries, Electric Wiring, Lighting, etc. In these pages the authors have succeeded in presenting the subjects in such manner as to overcome the hitherto insurmountable obstacle—higher mathematics. The rules and formulae are presented in a very simple manner, and special effort has been made to illustrate every principle by diagrams and practical examples.

¶ Numerous examples for practice are inserted at intervals; these with the test questions, help the reader to fix in mind the essential points, thus combining the advantages of a textbook with a reference work.

¶ Grateful acknowledgment is due to the corps of writers and collaborators who have prepared the many sections of this work. The hearty co-operation of these men—engineers of wide practical experience, and teachers of acknowledged ability—has alone made these volumes possible.

¶ The Cyclopedia is published in the belief that it will meet a real need among designers, constructors and operators of electrical machinery. That it may save many weary hours of search among the scattered textbooks and reference works of the day,—books which being intended largely for college-trained men are necessarily far from meeting the needs of the average practical man,—is the hope of the compilers and publishers.

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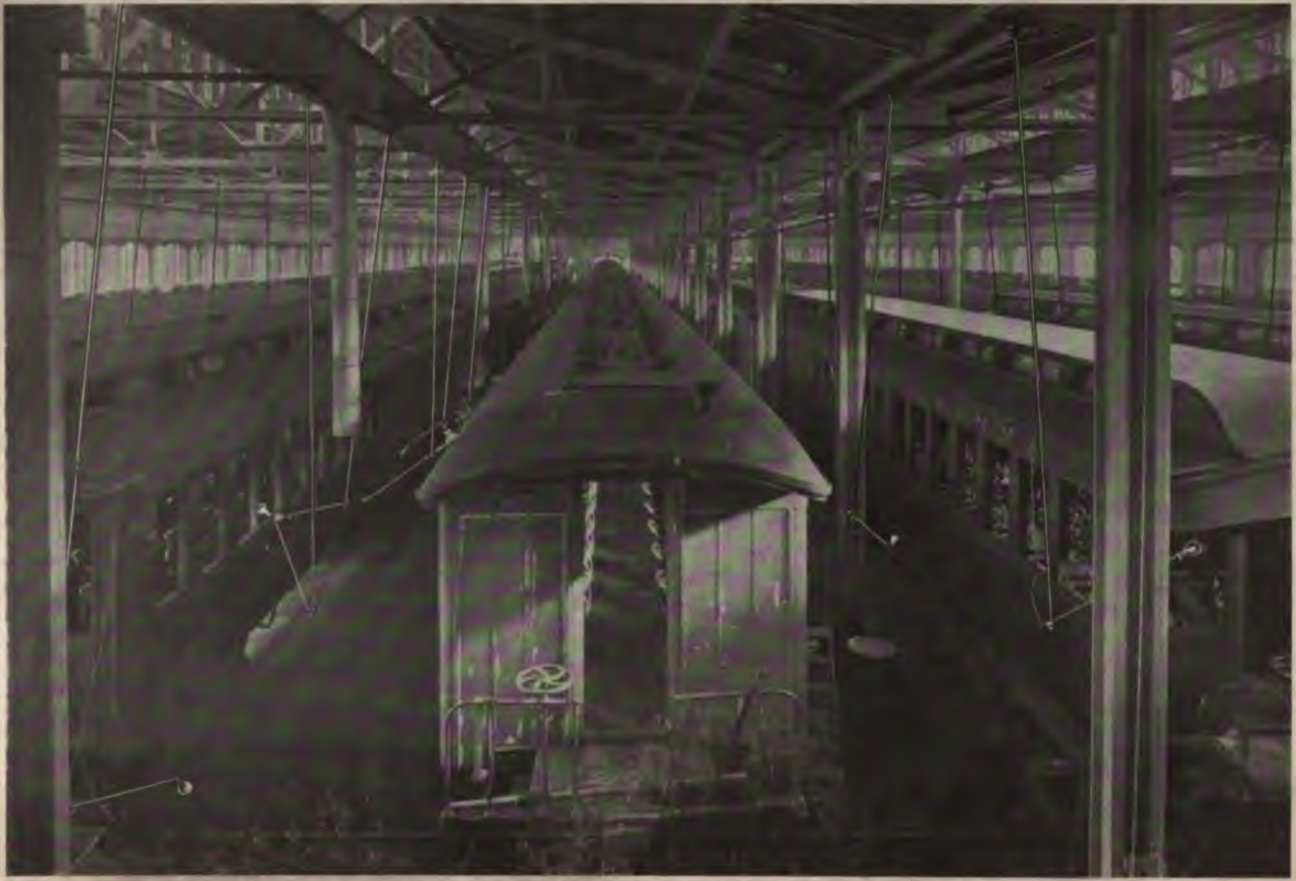

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Incandescent Lights Installed with White Adjustable Fixtures.

ELECTRIC LIGHTING.

HISTORY AND DEVELOPMENT.

The history of electric lighting as a commercial proposition begins with the invention of the Gramme dynamo (by Z. J. Gramme) in 1870, together with the introduction of the Jablochkoff candle or light, which was first announced to the public in 1876, and which formed a feature of the International Exposition at Paris in 1878. Up to this time, the electric light was known to but few investigators, one of the earliest being Sir Humphrey Davy who, in 1810, produced the first arc of any great magnitude. It was then called the "voltaic arc", and resulted from the use of two wood charcoal pencils as electrodes and a powerful battery of voltaic cells as a source of current.

From 1840 to 1859, many patents were taken out on arc lamps, most of them operated by clockwork, but these were not successful, due chiefly to the lack of a suitable source of current, since all depended on primary cells for their power. The interest in this form of light died down about 1859, and nothing further was attempted until the advent of the Gramme dynamo.

The incandescent lamp was but a piece of laboratory apparatus up to 1878, at which time Edison produced a lamp using a platinum spiral in a vacuum, as a source of light, the platinum being rendered incandescent by the passage of an electric current through it. The first successful carbon filament was made in 1879, this filament being formed from strips of bamboo. The names of Edison and Swan are intimately connected with these early experiments.

From this time on, the development of electric lighting has been very rapid, and the consumption of incandescent lamps alone has reached several millions each year. When we compare the small amount of lighting done by means of electricity twenty-five years ago with the enormous extent of lighting systems and the numerous applications of electric illumination as they are today, the growth and development of the art is seen to be very great, and the value of a study of this subject may be readily appreciated. While in many cases electricity is not the cheapest source of power for illumination, its admirable qualities and convenience of operation make it by far the most desirable.

Classification. The subject of Electric Lighting may be classified as follows:

1. The type of lamps used.
2. The methods of distributing power to the lamps.
3. The use made of the light, or its application.
4. Photometry and lamp testing.

Taking up these branches in the order named, we may further subdivide the types of lamps used into:

1. Incandescent lamps.
2. Arc lamps.
3. Special lamps, or lamps which do not require carbon, such as the Nernst lamp, Cooper-Hewitt lamp, etc.

The Incandescent Lamp. The incandescent lamp is by far the most common type of lamp used, and the principle of its operation is as follows:

If a current I is sent through a conductor whose resistance is R, for a time t, the conductor is heated, and the amount of heat generated is:

Heat generated $= I^2R\,t$, $I^2R\,t$ representing joules or watt-seconds.

If the current, material, and conditions are so chosen that the substance may be heated in this way until it gives out light, becomes incandescent, and does not deteriorate too rapidly, we have an incandescent lamp. Carbon is the substance chosen for this conductor and for ordinary lamps it is formed into a small thread or filament. Carbon is selected for two reasons:

1. The material must be capable of standing a very high temperature, 1280 to 1330° C.

2. It must be a conductor of electricity with a fairly high resistance.

Platinum has been used for the material, but, as we shall see, its temperature cannot be maintained at a value high enough to make the lamp as efficient as when carbon is used. Nearly all attempts to substitute another substance in place of carbon have failed, and the few lamps which are partially successful will be treated under the head of special lamps. The nature of the carbon employed in incandescent lamps has, however, been much improved over the first forms, and the method of manufacture will be treated next.

MANUFACTURE OF INCANDESCENT LAMPS.

Preparation of the Filament. Cellulose, a chemical compound rich in carbon, is prepared by treating absorbent cotton with zinc chloride in proper proportions to form a uniform, gelatine-like mass. It is customary to stir this under a partial vacuum in order to remove bubbles of air which might be contained in it and destroy its uniformity. This material is then forced, "squirted," through steel dies into alcohol, the alcohol serving to harden the soft, transparent threads. These threads are then thoroughly washed to remove all trace of the zinc chloride, dried, cut to the desired lengths, wound on forms, and carbonized by heating to a high temperature away from air. During carbonization, the cellulose is transformed into pure carbon, the volatile matter being driven off by the high temperature to which the filaments are subjected. The material becomes hard and stiff, assuming a permanent form, shrinking in both length and diameter; the form being specially constructed so as to allow for this shrinkage. The forms are made of carbon blocks which are placed in plumbago crucibles and packed with powdered carbon; the crucibles are covered with loosely fitting carbon covers. The crucibles are gradually brought to a white heat, at which temperature the cellulose is changed to carbon, and then allowed to cool. After cooling, the filaments are removed, measured and inspected, and the few defective ones discarded.

In the early days, these filaments were made of cardboard or bamboo, and later of thread treated with sulphuric acid.

A few of the shapes of filaments now in use are shown in Fig. 1, the different shapes giving a slightly diff ution
of light. The shapes here shown are designat
U-shaped; B, single-curl; C, single-curl
loop; E, double-curl; F, double-curl anc

Mounting the Filament. After carbonization, the filaments are mounted or joined to wires leading into the globe or bulb. These wires are made of platinum—platinum being the only substance, so far as known, that expands and contracts the same as glass with change in temperature and which, at the same time, will not be melted by the heat developed in the carbon. Since the bulb must remain air-tight, a substance expanding at a different rate from the glass cannot be used. Several methods of fastening the filament to the "leading in" wires have been used, such as forming a socket in the end of the wire, inserting the filament and then squeezing the socket tightly against the carbon, and the use of tiny bolts when cardboard filaments were used, but the pasted joint is now used almost exclusively. Finely powdered carbon is mixed with some adhesive compound, such as molasses, and this mixture is used as a paste for fastening the carbon to the platinum. Later, when current is sent through the joint, the volatile matter is driven off and only the carbon remains. This makes a cheap and, at the same time, a very efficient joint.

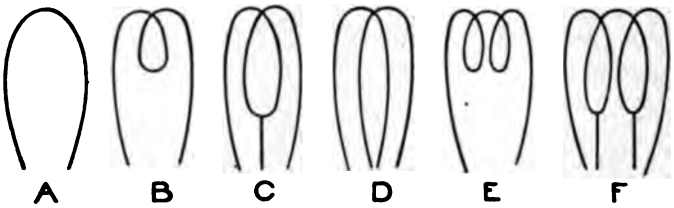


Fig. 1.

Flashing. Filaments, prepared and mounted in the manner just described, are fairly uniform in resistance, but it has been found that their quality may be much improved and their resistance very closely regulated by depositing a layer of carbon on the outside of the filament by the process of "flashing". By flashing is meant heating the filament to a high temperature when immersed in a hydrocarbon gas, such as gasoline vapor, under partial vacuum. Current is passed through the filament in this process to accomplish the heating. Gas is used, rather than a liquid, to prevent too heavy a deposit of the carbon. Coal gas is not recommended because the carbon, when deposited from this, has a dull black appearance. The effects of flashing are as follows:

1. The diameter of the filament is increased by the deposited carbon and hence its resistance is decreased. The process must be discontinued when the desired resistance is reached. Any little irregularities in the filament will be eliminated since the smaller sections, having the greater resistance, will become hotter than the remainder of the filament and the carbon is deposited more rapidly at these points.

2. The character of the surface is changed from a dull black and comparatively soft nature to a bright gray coating which is much harder and which increases the life and efficiency of the filament.

Exhausting. After flashing, the filament is sealed in the bulb and the air exhausted through the tube A in Fig. 2, which shows the lamp in different stages of its manufacture. The exhaustion is accomplished by means of mechanical air pumps, supplemented by Sprengle or mercury pumps and chemicals. Since the degree of exhaustion must be high, the bulb should be heated during the process so as to drive off any gas which may cling to the glass. When chemicals are used, as is now almost universally the case, the chemical is placed in the tube A and, when heated, serves to take up much of the remaining gas. Exhaustion is necessary for several reasons:

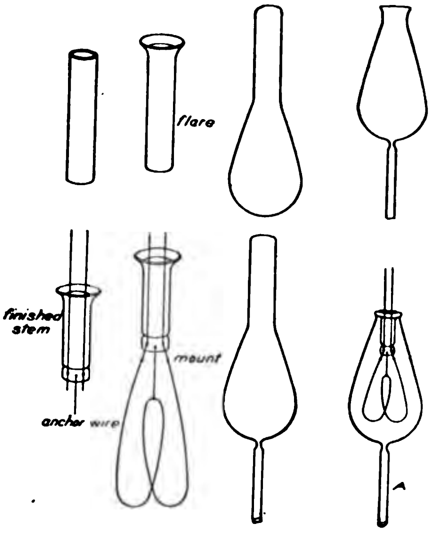


Fig. 2.

1. To avoid oxidization of the filament.
2. To reduce the heat conveyed to the globe.
3. To prevent wear on the filament due to currents or eddies in the gas.

After exhausting, the tube A is sealed off and the lamp completed for testing by attaching the base by means of plaster of Paris. Fig. 3 shows some of the forms of completed incandescent lamps.

Voltage and Candle-Power. Incandescent lamps vary in size from the miniature battery and candelabra lamps to those of several hundred candle-power, though the latter are very seldom used. The more common values for the candle power are 8, 16, 25, 32, and 50, the choice of candle-power depending on the use to be made of the lamp.

The voltage will vary depending on the method of distribution of the power. For what is known as parallel distribution, 110 or 220 volts are generally used. For the higher values of the voltage, long and slender filaments must be used, if the candle-power is to be low, and lamps of less than 16 candle-power for 220-volt circuits are not practical, owing to difficulty in manufacture. For series distribution, a low voltage and higher current is used, hence the filaments may be quite heavy. Battery lamps operate on from 4 to 24 volts, but the vast majority of lamps for general illumination are operated at or about 110 volts.

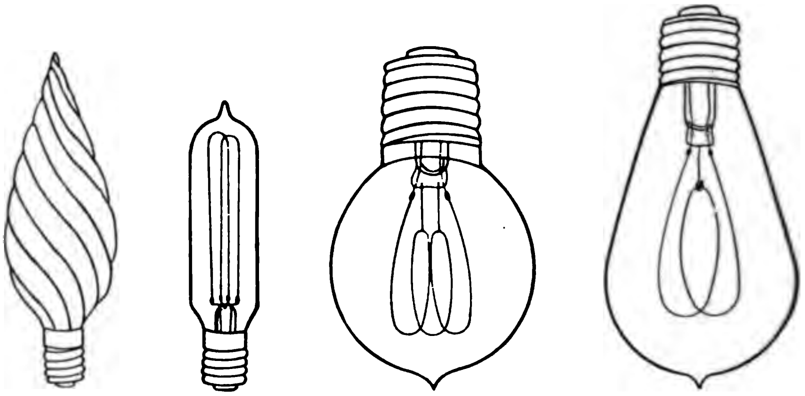


Fig. 3.

Efficiency. By the efficiency of an incandescent lamp is meant the power required at the lamp terminals per candle-power of light given. Thus, if a lamp giving an average horizontal candle-power of 16 consumes $\frac{1}{2}$ an ampere at 112 volts, the total number of watts consumed will be $112 \times \frac{1}{2} = 56$, and the watts per candle-power will be $56 \div 16 = 3.5$. The efficiency of such a lamp is said to be 3.5 watts per candle-power. "Watts economy" is sometimes used for "efficiency".

The efficiency of a lamp depends on the temperature at which the filament is run. This temperature is between 1280° and 1330° C, and the curve in Fig. 4 shows the increase of efficiency with the increase of temperature. The temperature attained by a filament depends on the rate at which heat is radiated and the amount of power supplied. The rate of radiation of heat is proportional to the area of the filament, the elevation in temperature, and the emissivity of the surface.

By emissivity is meant the number of heat units emitted from unit surface per degree rise in temperature above that of surrounding bodies. The bright surface of a flashed filament has a lower emissivity than the dull surface of an unheated filament, hence less energy is lost in heat radiation and the efficiency of the filament is increased.

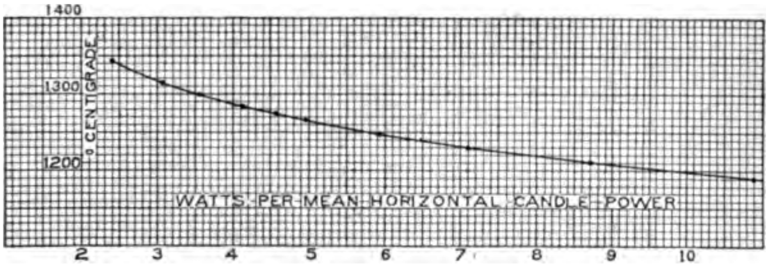


Fig. 4.

As soon as incandescence is reached, the illumination increases much more rapidly than the emission of heat, hence the increase in efficiency shown in Fig. 4. Were it not for the rapid disintegration of the carbon at high temperature, an efficiency higher than 3.1 watts could be obtained.

Relation of Life to Efficiency. By the useful life of a lamp is meant the length of time a lamp will burn before its candle-power has decreased to such a value that it would be more economical to replace the lamp with a new one than to continue to use it at its decreased value. A decrease to 80% of the initial candle-power is now taken as the point at which a lamp should be replaced, and the normal life of a lamp is in the neighborhood of 800 hours. To obtain the most economical results, lamps should always be replaced at the end of their useful life.

In Table 1 are given values of the efficiency and life of a 3.5-watt, 110-volt lamp for various voltages impressed on the lamp. These values are plotted in Fig. 5. These curves show that a 3% increase of voltage on the lamp reduces the life by one-half, while an increase of 6% causes the useful life to fall to one-third its normal value. The effect is even greater when 3.1-watt lamps are used, but not so great with 4-watt lamps. From this we see that the regulation of the voltage used on the system must be very good if high efficiency lamps are to be used, and this regulation will determine the type of lamp to be installed.

Selection of Lamps. Lamps taking 3.1 watts per candle-power will give satisfaction only when the regulation of voltage is the best- -practically a constant voltage maintained at the normal voltage of the lamp.

TABLE I.

Effects of Change in Voltage.

Standard 3.5 Watt Lamp.

Voltage Per Cent. of Normal.	Candle-Power Per Cent. of Normal.	Watts Per Candle-Power.	Life Per Cent. of Normal.	Deterioration Per Cent. of Normal.
90	53	5.36		
91	56	5.09		
92	61	4.85		
93	65	4.63		
94	69	4.44	394	25
95	73	4.26	310	32
96	78	4.09	247	44
97	83	3.93	195	51
98	88	3.78	153	65
99	94	3.64	126	79
100	100	3.5	100	100
101	106	3.33	84	118
102	111	3.27	68	146
103	116	3.16	58	173
104	123	3.05	47	211
105	129	2.95	39	253
106	137	2.85	31	316
107	143	2.76	26	380
108	152	2.68	21	474
109	159	2.60	17	575
110	167	2.53	16	637

Lamps of 3.5 watts per candle-power should be used when the regulation is fair, say with a maximum variation of 2% from the normal voltage.

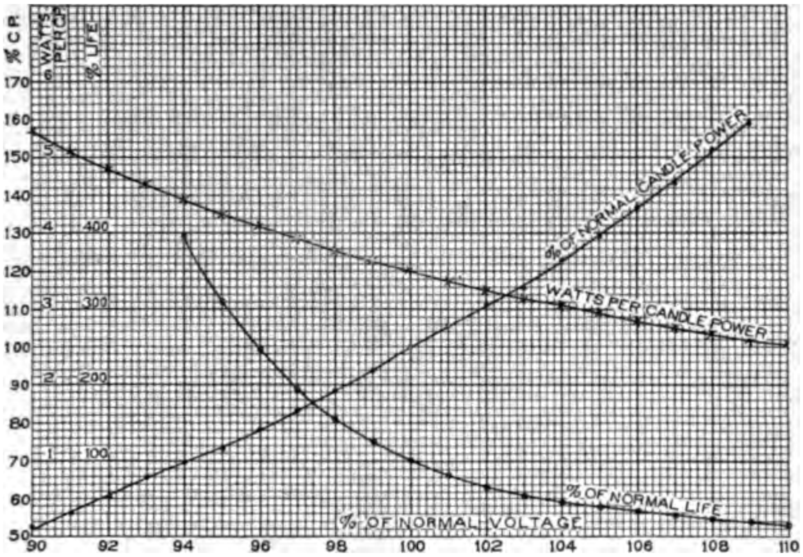


Fig. 5.

Lamps of 4 watts per candle-power should be installed when the regulation is poor. These values are for 110-volt lamps. A 220-volt lamp should have a lower efficiency to give a long life.

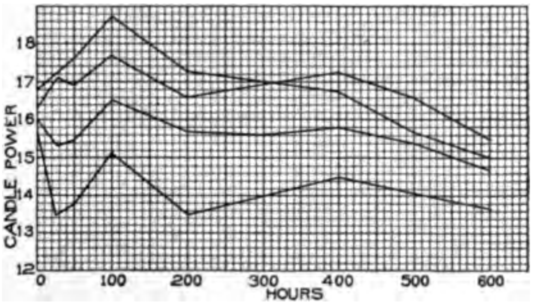


Fig. 6.

Lamps should always be renewed at the end of their useful life, this point being termed the "smashing point", as it is cheaper to replace the lamp than to run it at the reduced candle-power. Some recommend running these lamps at a higher voltage, but that means at a reduced efficiency, and it is not good practice to do this.

Fig. 6 shows the life curves of a series of incandescent lamps. These curves show that there is an increase in the candle-power of some of the lamps during the first 100 hours, followed by a period during which the value is fairly constant, after which the light given by the lamp is gradually reduced to about 80% of the initial candle-power.

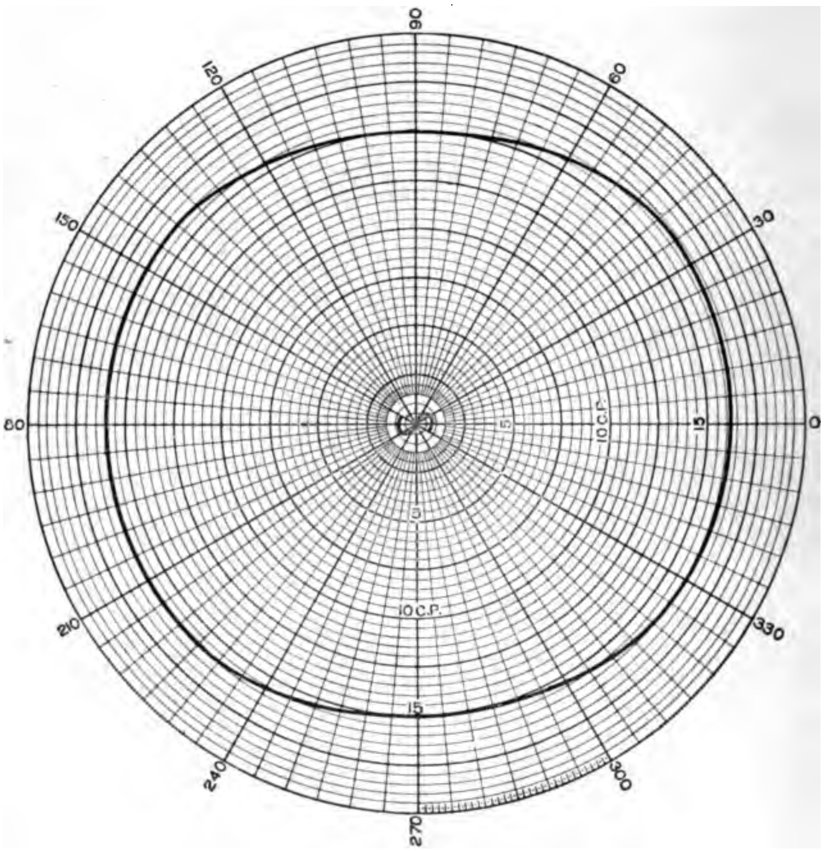


Fig. 7.

DISTRIBUTION OF LIGHT.

In Fig. 1 are shown various forms of filaments used in incandescent lamps, and Figs. 7 and 8 show the distribution of light from a single-loop filament of cylindrical cross-section.

Fig. 7 shows the distribution of light in a horizontal plane, the lamp being mounted in a vertical position, and Fig. 8 shows the distribution in a vertical plane. By changing the shape of the filament, the light distribution is varied. A mean of the readings taken in the horizontal plane forms the *mean horizontal candle-power*, and this candle-power rating is the one generally assumed for the ordinary incandescent lamp. A mean of the readings taken in a vertical plane gives us the mean vertical candle-power, but this value is of little use.

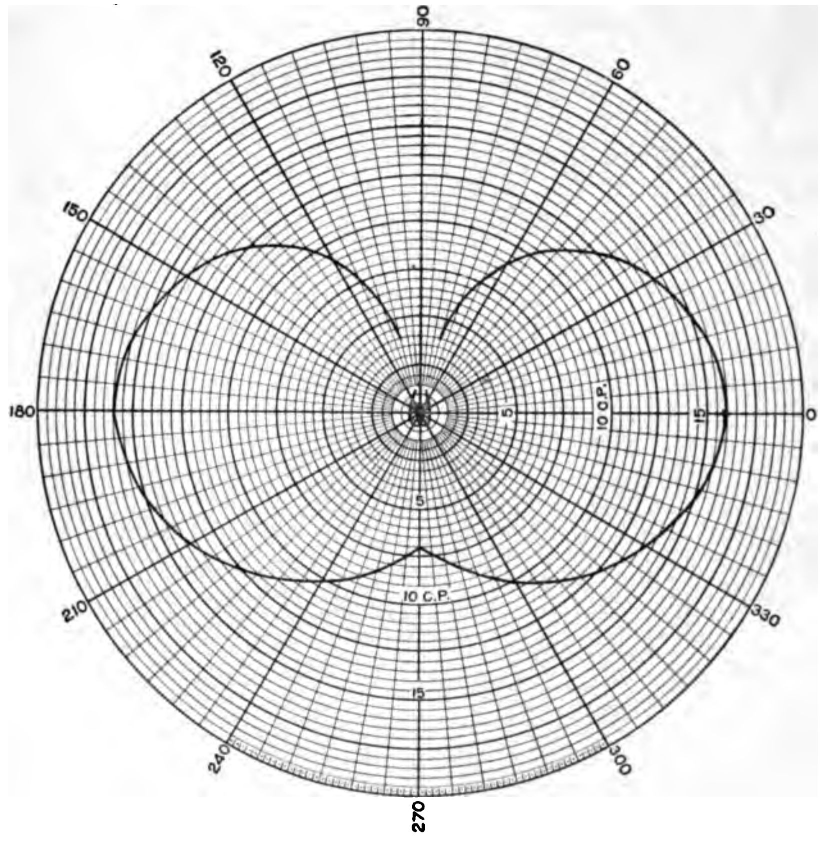


Fig. 8.

Mean Spherical Candle-Power. When comparing lamps which give an entirely different light distribution, the mean horizontal candle-power does not form a proper basis for such comparison, and the mean spherical or the mean hemispherical candle-power is used instead. By mean spherical candle-power is meant a mean value of the light taken in all directions. The methods for determining this will be taken up under *photometry*. The mean hemispherical candle-power has reference, usually, to the light given out below the horizontal plane.

ARC LAMPS.

The Electric Arc. Suppose two carbon rods are connected in an electric circuit, and the circuit closed by touching the tips of these rods together; on separating the carbons again the circuit will not be broken, provided the space between the carbons be not too great, but will be maintained through the arc formed at these points. This phenomenon, which is the basis of the arc light, was first observed on a large scale by Sir Humphrey Davy, who used a battery of 2,000 cells and produced an arc between charcoal points four inches apart.

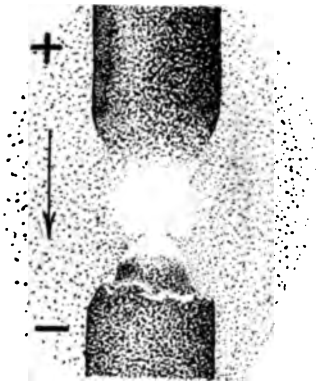


Fig. 9.

As the incandescence of the carbons across which an arc is maintained, together with the arc itself, forms the source of light for all arc lamps, it will be well to study the nature of the arc. Fig. 9 shows the general appearance of an arc between two carbon electrodes when maintained by direct current.

Here the current is assumed as passing from the top carbon to the bottom one as indicated by the arrow and signs. We find, in the direct-current arc, that the most of the light issues from the tip of the positive carbon, or electrode, and this portion is known as the *crater* of the arc. This crater has a temperature of from 3,000 to 3,500° C, the temperature at which the carbon vaporizes, and gives fully 80 to 85% of the light furnished by the arc. The negative carbon becomes pointed at the same time that the positive one is hollowed out to form the crater, and it is also incandescent but not to as great a degree as the positive carbon.

Between the electrodes there is a band of violet light, the arc proper, and this is surrounded by a luminous zone of a golden yellow color. The arc proper does not furnish more than 5% of the light emitted.

The carbons are worn away or consumed by the passage of the current, the positive carbon being consumed about twice as rapidly as the negative.

The light distribution curve of a *direct-current arc*, taken in a vertical plane, is shown in Fig. 10. Here it is seen that the maximum amount of light is given off at an angle of about 50° from the vertical, the negative carbon shutting off the rays of light that are thrown directly downward from the crater.

If alternating current is used, the upper carbon becomes positive and negative alternately, and there is no chance for a crater to be formed, both carbons giving off the same amount of light and being consumed at about the same rate. The light distribution curve of an *alternating-current arc* is shown in Fig. 11.

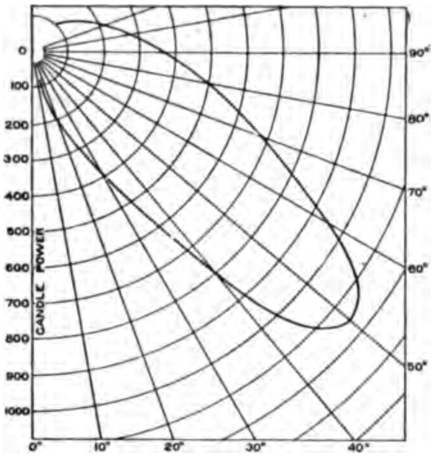


Fig. 10.

Arc Lamp Mechanisms. In a practical lamp we must have not only a pair of carbons for producing the arc, but also means for supporting these carbons, together with suitable arrangements for leading the current to them and for maintaining them at the proper distance apart. The carbons are kept separated the proper distance by the operating mechanisms which must perform the following functions :

1. The carbons must be in contact, or be brought into contact, to start the arc when the current first flows.
2. They must be separated at the right distance to form a proper arc immediately afterward.
3. The carbons must be fed to the arc as they are consumed.
4. The circuit should be open or closed when the carbons are entirely consumed, depending on the method of power distribution.

The feeding of the carbons may be done by hand, as is the case in some stereopticons using an arc, but for ordinary illumination the striking and maintaining of the arc must be automatic. It is made so in all cases by means of solenoids acting against the force of gravity or against springs. There are an endless number of such mechanisms, but a few only will be described here. They may be roughly divided into three classes:

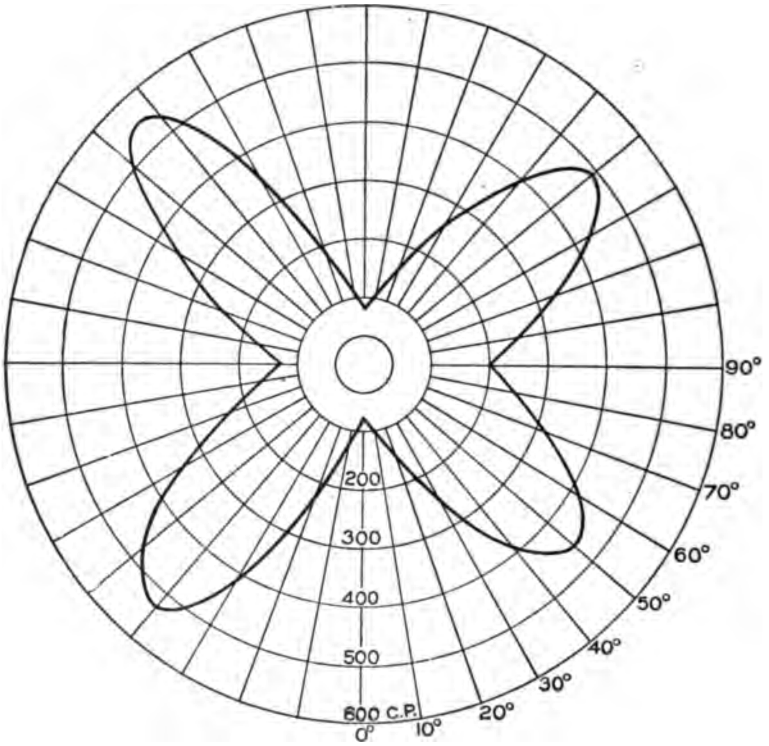


Fig. 11.

1. Shunt Mechanisms.
2. Series Mechanisms.
3. Differential Mechanisms.

In **Shunt Lamps**, the carbons are held apart before the current is turned on, and the circuit is closed through a solenoid connected in across the gap so formed. All of the current must pass through this coil at first, and the plunger of the solenoid is arranged to draw the carbons together, thus starting the arc. The pull of the solenoid and that of the springs are adjusted to maintain the arc at its proper length.

Such lamps have the disadvantage of a high resistance at the start—450 ohms or more—and are difficult to start on series circuits, due to the high voltage required. They tend to maintain a constant voltage at the arc, but do not aid the dynamo in its regulation, so that the arcs are liable to be a little unsteady.

With the **Series-Lamp Mechanism**, the carbons are together when the lamp is first started and the current, flowing in the series coil, separates the electrodes, striking the arc. When the arc is too long, the resistance is increased and the current lowered so that the pull of the solenoid is weakened and the carbons feed together. This type of lamp can be used only on constant-potential systems.

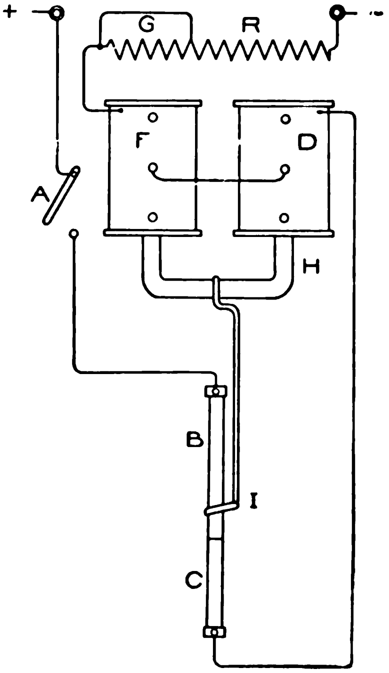


Fig. 12.

Fig. 12 shows a diagram of the connection of such a lamp. This diagram is illustrative of the connection of one of the lamps manufactured by the Western Electric Company, for use with direct current on a constant-potential system. The symbols + and — refer to the terminals of the lamp, and the lamp must be so connected that the current flows from the top carbon to the bottom one. R is a series resistance, adjustable for different voltages by means of the shunt G. F and D are the controlling solenoids connected in series with the arc. B and C are the positive and negative carbons respectively, while A is the switch for turning the current on and off. H is the plunger of the solenoids and I the carbon clutch, this being what is known as a "carbon feed" lamp. The carbons are together when A is first closed, the current is excessive, and the plunger is drawn up into the solenoids, lifting the carbon B until the resistance of the arc lowers the current to such a value that the pull of the solenoid just counterbalances the weight of the plunger and carbon. G must be so adjusted that this point is reached when the arc is at its normal length.

In the **Differential Lamp**, the series and shunt mechanisms are combined, the carbons being together at the start, and the series coil arranged so as to separate them while the shunt coil is connected across the arc, as before, to prevent the carbons from being drawn too far apart. This lamp operates only over a low-current range, but it tends to aid the generator in its regulation.

Fig. 13 shows a lamp having a differential control, this also being the diagram of a Western Electric Company arc lamp for direct-current, constant-potential system. Here S represents the shunt coil and M the series coil, the armature of the two magnets A and A′ being attached to a bell-crank, pivoted at B, and attached to the carbon clutch C. The pull of coil S tends to lower the carbon while that of M raises the carbon, and the two are so adjusted that equilibrium is reached when the arc is of the proper length. All of the lamps are fitted with an air dashpot or some damping device to prevent too rapid movements of the working parts.

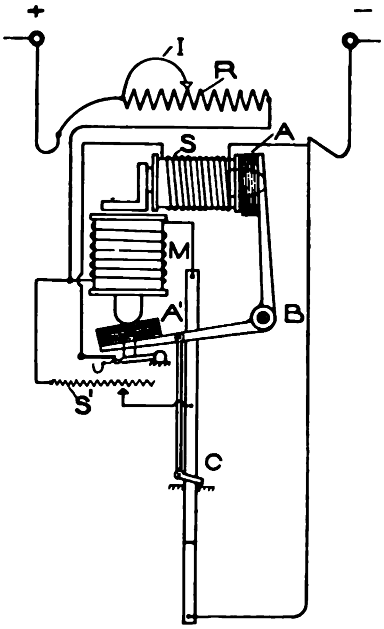
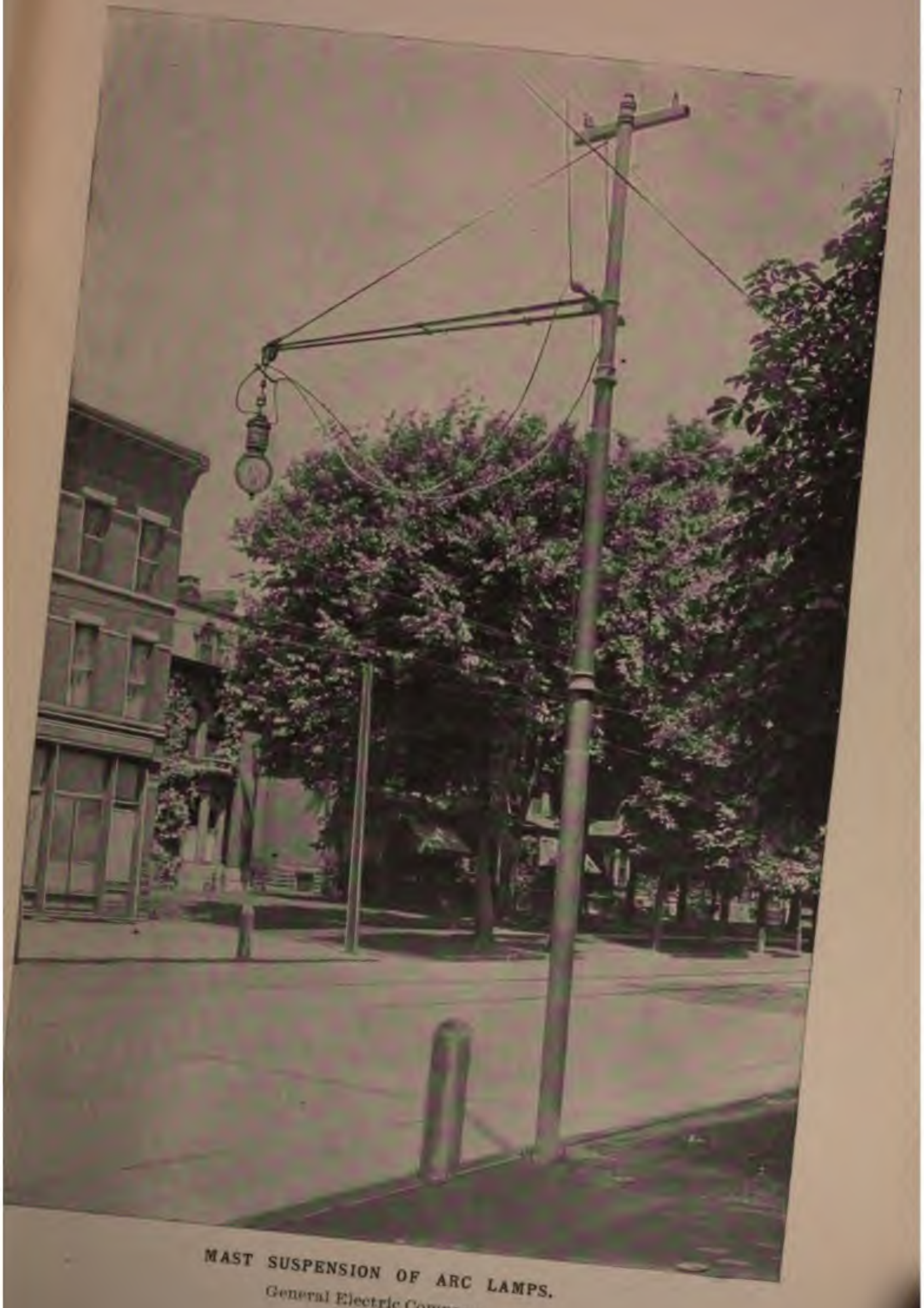


Fig. 13.

The methods of supporting the carbons and feeding them to the arc may be divided into two classes:

1. Rod feed.
2. Carbon feed.

Lamps using a **Rod Feed** have the upper carbons supported by a conducting rod, and the regulating mechanism acts on this rod,



MAST SUSPENSION OF ARC LAMPS.

General Electric Company.

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the current being fed to the rod by means of a sliding contact. Fig. 14 shows the arrangement of this type of feed. The rod is shown at R, the sliding contact at B, and the carbon is attached to the rod at C.

These lamps have the advantage that carbons, which do not have a uniform cross-section or smooth exterior, may be used, but they possess the disadvantage of being very long in order to accommodate the rod. The rod must also be kept clean so as to make a good contact with the brush.

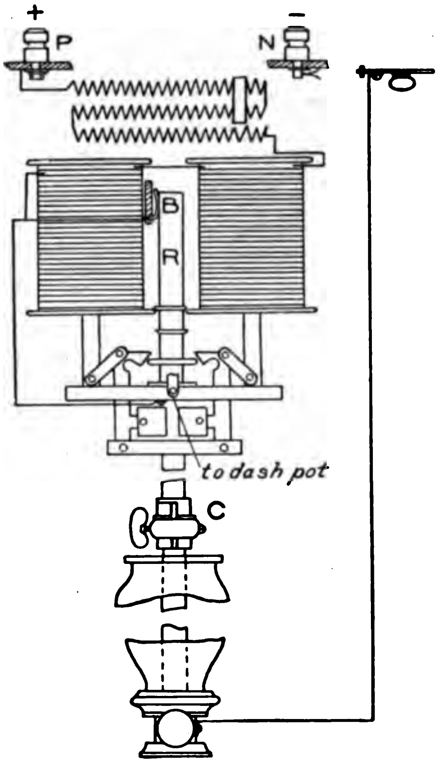

Fig. 14.

In **Carbon-Feed** lamps the controlling mechanism acts on the carbons directly through some form of clutch such as is shown at C in Fig. 15. This clamp grips the carbon when it is lifted, but allows the carbon to slip through it when the tension is released. For this type of feed the carbon must be straight and have a uniform cross-section as well as a smooth exterior. The current may be led to the carbon by means of a flexible lead and a short carbon holder.

Double-Carbon Lamps. In order to increase the life of the early form of arc lamp without using too long a carbon, the double-carbon type was introduced. This type uses two sets of carbons, both sets being fed by one mechanism so arranged that when one pair of the electrodes is consumed the other is put into service. With the introduction of the enclosed arcs, this form of lamp is rapidly disappearing, although a few are still in use.

Arc lamps are constructed to operate on *Direct Current* or *Alternating Current* systems when connected in *Series* or in *Multiple*. They are also made in both the *Open* and the *Enclosed* forms, but almost all of the lamps operating on alternating current or on constant-potential, direct current are enclosed.

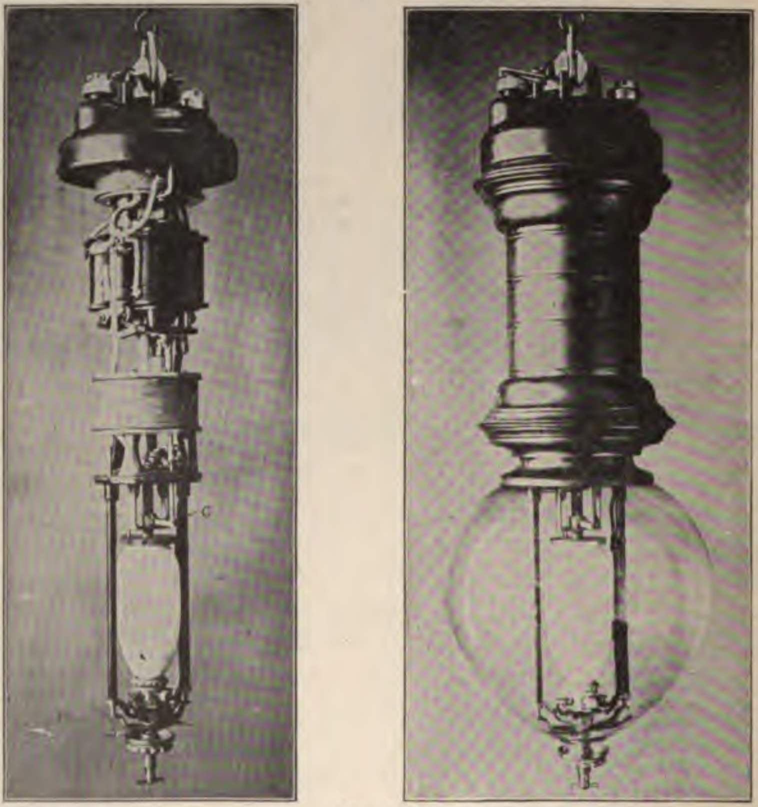

Fig. 15.

By an *Open Arc* is meant an arc lamp in which the arc is exposed to the atmosphere, while in the *Enclosed Arc* an inner or enclosing globe surrounds the arc, and this globe is covered with a cap which renders it nearly air-tight. Fig. 15 is a good example of an enclosed arc as manufactured by the General Electric Company.

Open Arcs for direct-current systems were the first to be used to any great extent, and they are used considerably at present, although they are being rapidly replaced by the enclosed types or the alternating-current systems. They are always connected in series, and are run from some form of special arc machine, a description of which may be found in "Types of Dynamo Electric Machinery".

Each lamp requires in the neighborhood of 50 volts for its operation, and, since the lamps are connected in series, the voltage of the system will depend on the number of lamps; therefore, the number of lamps that may be connected to one machine is limited by the maximum allowable voltage on that machine. By special construction as many as 125 lamps are run from one machine, but even this size of generator is not so efficient as one of greater capacity. Such generators are usually wound for 6.6 or 9.6 amperes. Since the carbons are exposed to the air at the arc, they are rapidly consumed, requiring that they be renewed daily for this type of lamp.

Enclosed Direct-Current Arc Lamps for series systems are constructed much the same as the open lamp, and are controlled by either shunt or differential mechanism. They require a voltage from 68 to 75 at the arc, and are usually constructed for from 5 to 6.8 amperes. They also require a constant-current generator.

Arc Lamps for Constant-Potential direct-current systems must have some resistance connected in series with them to keep the voltage at the arc at its proper value. This resistance is made adjustable so that the lamps may be used on any circuit. Its location is clearly shown in Fig. 15, one coil being located above, the other below the operating solenoids.

Arc Lamps for Alternating Currents do not differ greatly in construction from the direct-current arcs. When iron or other metal parts are used in the controlling mechanism, they must be laminated or so constructed as to keep down induced or eddy currents which might be set up in them. For this reason the metal spools, on which the solenoids are wound, are slotted at some point to prevent them from forming a closed secondary to the primary formed by the solenoid winding. On constant potential circuits a reactive coil is used in place of a part of the resistance for cutting down the voltage at the arc.

Interchangeable Arc Lamps are manufactured which may be readily adjusted so as to operate on either direct or alternating current, and on voltages from 110 to 220. Two lamps may be run in series on 220-volt circuits.

The distribution of light, and the resulting illumination for the different lamps just considered, will be taken up later. Aside from the distribution and quality of light, the enclosed arc has the advantage that the carbons are not consumed so rapidly as in the open lamp because the oxygen is soon exhausted from the inner globe and the combustion of the carbon is greatly decreased. They will burn from 80 to 100 hours without re-trimming.

TABLE 2.

		Watts Consumed.					Mean Intensity in H. U.			Mean Watts.		
							Spherical.		Lower Hemi-spherical	Spherical H. U.		Lower Hemi-spherical
D. C. Lamp.	Current.	In Lamp.		In Arc.		Mechanism.	Op. Outer.	Clear Outer	Clear Outer.	Op. Outer.	Clear Outer.	Clear Outer.
								235	332		2.87	1.66
1	5.01	551		401		150	172	256*	362*	3.10	2.18*	1.52*
3	5.08	559		406		252	195	216	282	2.85	2.60	1.99
4	4.76	524		381		143	127	139	208	4.12	3.76	2.52
5	4.16†	458		333		125	154	174	221	2.96	2.63	2.07
7	4.76	524		381		143	203	333	317	2.63	2.20	1.65
9	4.84	532		387		145	182	226	281	2.83	2.38	1.89
10	4.99	549		399		150	202	242	309	2.74	2.24	1.77
12	4.87	536		390		146	178	195	230	3.05	2.66	2.38
Mean	4.9	529		384		144	176	207	272	3.03	2.60	1.98
A. C. Lamp.	Current.	In Lamp.	Power Factor Lamp.	In Arc.	Power Factor Arc.	Mechanism.						
101	6.40	448	.63	340	.82	108	127	141	206	3.52	3.17	2.17
								203	236		2.26	1.94
102	6.79	459	.61	375	.73	84	146	176†	226†	3.31	2.60†	1.72†
103	5.89	424	.65	344	.75	80	116	130	147	3.66	3.15	2.88
105	6.20	414	.61	382	.80	32	128	187	219	3.24	2.20	1.89
								153	169		2.56	2.23
106	6.12	378	.56	298	.70	80	132	182†	284	2.82	2.19†	1.48†
108	6.48	457	.64	383	.80	71.5	133	175	211	3.20	2.61	2.16
110	6.18	339	.49	276	.72	63	140*	126	143	2.41*	2.68	2.37
Mean	6.29	417	.60	342	.76	74.5	130	159	190	3.31	2.66	2.23

*Condition of no outer globe. †Condition with shade on lamp. H. U Hefner Units.

Rating of Arc Lamps. Open arcs have been classified as follows:

Full Arcs, 2,000 candle-power taking 9.5 to 10 amps. or 450–480 watts.
Half Arcs, 1,200 candle-power taking 6.5 to 7 amps. or 325–350 watts.

These candle-power ratings are much too high, and run more nearly 1,200 and 700, respectively, for the point of maximum intensity and less than this if the mean spherical candle-power be taken. For this reason, the ampere or watt rating is now used to indicate the power of the lamp. Enclosed arcs use from 3 to 6.5 amperes, but the voltage at the arc is higher than for the open lamp. Table 2 gives some data on enclosed arcs on constant-potential circuits.

Efficiency. The efficiency of arc lamps is given as follows:

Direct Current Arc (enclosed) 2.9 watts per candle-power.
Alternating Current Arc (enclosed) 2.95 watts per candle-power.
Direct Current Arc (open) .6–1.25 watts per candle-power.

Arc-Lamp Carbons are either moulded or forced from a product known as petroleum coke or from similar materials such as lampblack. The material is thoroughly dried by heating to a high temperature, then ground to a fine powder and combined with some substance such as pitch which binds the fine particles of carbon together. After this mixture is again ground it is ready for moulding. The powder is put in steel moulds and heated until it takes the form of a paste, when the necessary pressure is applied to the moulds. For the forced carbons, the powder is formed into cylinders which are placed in machines which force the material through a die so arranged as to give the desired diameter. The forced carbons are often made with a core of some special material, this core being added after the carbon proper has been finished. The carbons, whether moulded or forced, must be carefully baked to drive off all volatile matter. The forced carbon is always more uniform in quality and cross-section, and is the type of carbon which must be used in the carbon feed lamp. The adding of a core of a different material seems to change the quality of light, and being more readily volatilized, keeps the arc from wandering.

Plating of carbons with copper is sometimes resorted to for moulded forms for the purpose of increasing the conductivity, and, by protecting the carbon near the arc, prolonging the life.

SPECIAL LAMPS.

Under this heading may be considered all lamps wh
not use carbon as the incandescent material, as well as

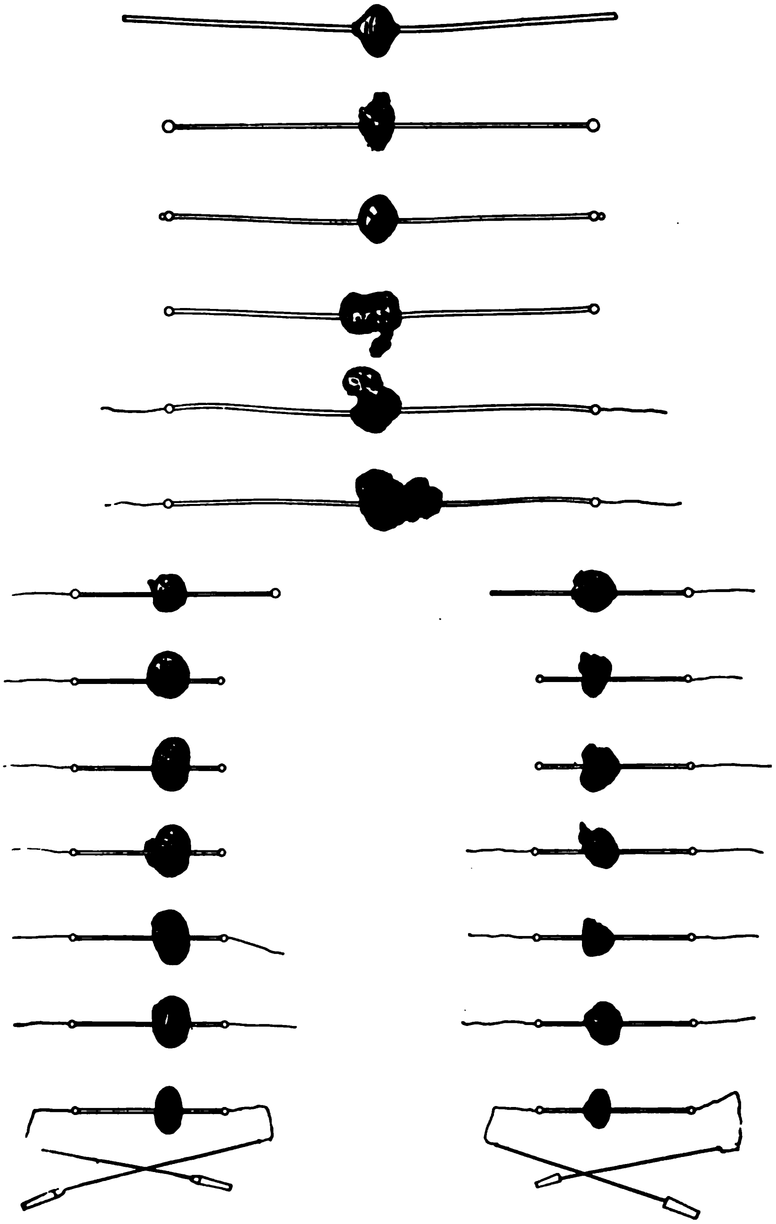

Fig. 16.

which use carbon in conjunction with other materials. The first of these lamps, or the one at present most widely used, is the Nernst Lamp.

The Nernst Lamp is an incandescent lamp using for the incandescent material certain oxides of the rare earths. The oxide is mixed in the form of a paste, then squirted through a die into a string which is subjected to a roasting process forming the filament or *glower* material of the lamp. The glowers are cut the desired length and platinum terminals attached. The attachment of these terminals to the glowers is a very important process in the manufacture of the lamp, and is accomplished by fusing the ends of the glower and the platinum lead into small beads, and, when the two are brought into contact, the platinum is sucked up into the glower head, forming a very neat and efficient connection. Fig. 16 shows several completed glowers.

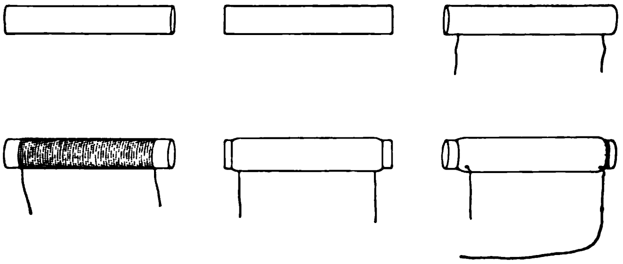

Fig. 17.

As the glower is a non-conductor when cold, some form of *heater* is necessary to bring it up to a temperature at which it will conduct. Two forms of heater are used, the first being formed of fine platinum wire wound over a porcelain tube as a support and covered with porcelain paste to prevent deterioration as much as possible. These "heater tubes", as they are called, are mounted just above the glowers in the finished lamp. The second form of heater is known as the "spiral heater", and this is also made of fine platinum wire wound on a porcelain rod and covered with paste, the rod being then formed on a mandrel to the desired shape. Figs. 17 and 18 show the two forms of heaters.

The heating device is connected across the circuit when the lamp is first turned on, and it must be cut out of circuit automatically when the glower becomes a conductor, otherwise the heater would soon be destroyed. This automatic *cut-out* is operated by means of an electromagnet so arranged that current flows through its coil as soon as the glower conducts and opens a form of silver contact cutting out the heater. The heater circuit is normally kept closed by the force of gravity so that the lamps will operate only in one position. A successful form of universal cut-out, that is, one which will operate when the lamp is in any position, has not yet been put on the market, though experiments with this type are being made.

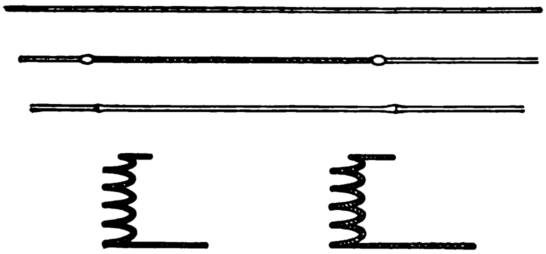

Fig. 18.

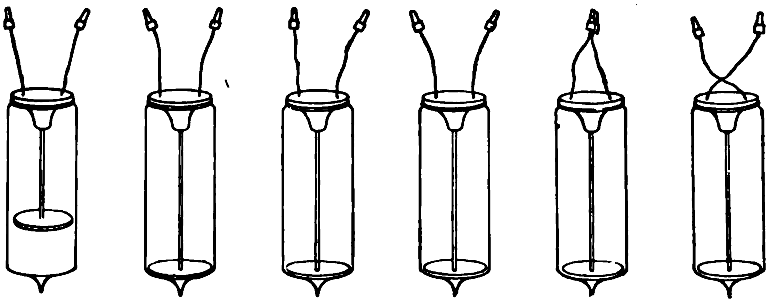

Fig. 19.

The conductivity of the glower increases with its temperature ; hence, if used on a constant-potential circuit directly, its temperature would continue to increase, due to the greater current flowing, until the glower was destroyed. To prevent this increase of current, a *ballast resistance* of fine iron wire is connected in series with the glower. As is well known, the resistance of iron wire increases quite rapidly with increase of temperature, and this resistance is so adjusted that the resistance of the combined circuit reaches a constant value when the current is of the proper strength. This iron wire must be protected from the air to prevent oxidization and too rapid temperature changes, and, for this reason, it is mounted in a glass bulb filled with hydrogen. Hydrogen has been selected for this purpose because it is an inert gas and conducts the heat from the ballast to the walls of the bulb better than other gases. Fig. 19 shows the form of bulb which contains the ballast.

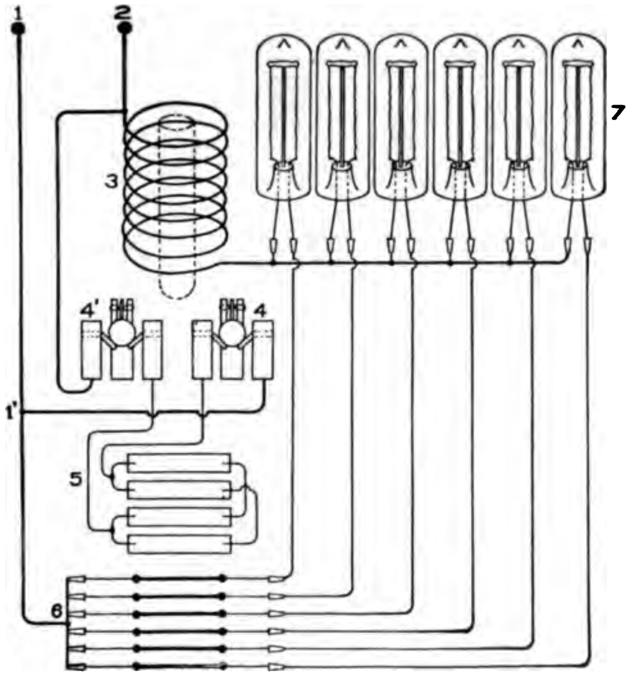

Fig. 20.

All of the parts enumerated, namely, glower, heater, cut-out and ballast, are mounted in a suitable manner, the smaller lamps having but one glower and arranged to fit an incandescent lamp socket, while the larger types have as many as six glowers and are arranged to be supported in a manner similar to arc lamps. All of the parts are interchangeable and may be easily renewed.

Fig. 20 shows the complete connections of a six-glower lamp. Current enters the lamp at terminal 1 (or 2), passes through the

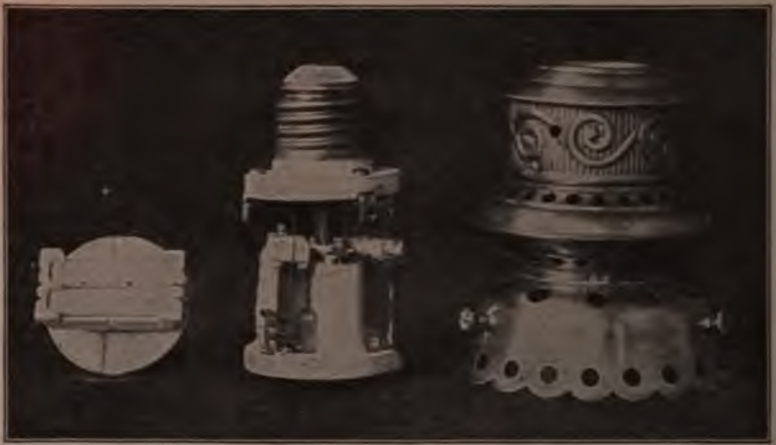

Fig. 21.

contacts of the cut-out 4, to the heater circuit 5, then to the contacts 4′ and to terminal 2. When the glowers become hot enough to conduct, the current divides at 1′, part of it going through the glowers 6, the ballast 7, and the cut-out coil 3 to terminal 2. By the time the current in the glower has reached its normal value, the contacts at 4 and 4′ have opened, cutting out the heater coils

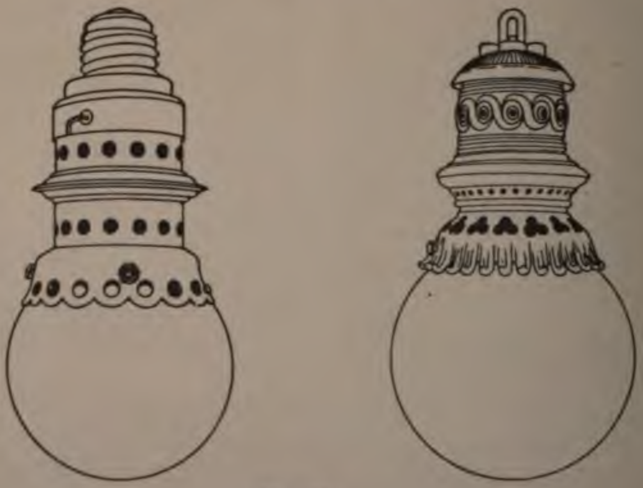

Fig. 23.

entirely. The heaters are so arranged that if one is destroyed, the other two will heat the glowers as quickly as possible.

Fig. 21 shows the parts of a single-glower lamp with the exception of the globe. Fig. 22 illustrates a six-glower street lamp. Fig. 23 shows lamps for inside use completely assembled Fig. 24 shows a glower and spiral heater so mounted that the two may be very readily replaced. This type is used on some of the very latest forms of lamps put on the market by the Nernst Lamp Company of Pittsburg, which company controls the manufacture of these lamps in the United States.

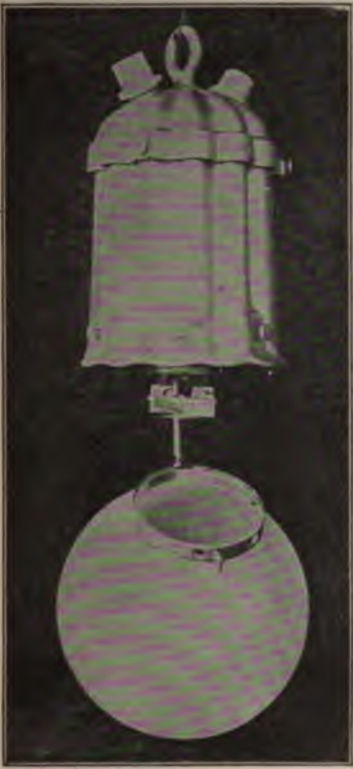

Fig. 22.

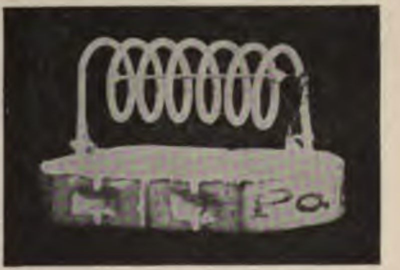

Fig. 24.

This type of lamp is used extensively only on alternating-current circuits at a frequency of about 60 cycles, and preferably at 220 volts, as the efficiency is better at this voltage, due to less energy being consumed in the ballast. Series lamps, and lamps operated on direct current, are still in the experimental stage.

The advantages claimed for the Nernst lamp are increased efficiency, a good color of light, and a good light distribution. The efficiency varies with the type and the voltage used, as well as with the direction in which the candle-power is measured and the type of globe used. For a 100-hour run on a two-glower, 220-volt lamp using a 6-inch light sand-blasted globe, the watts varied from 170 to 158, while the mean hemispherical candle-power varied from 67.8 to 50.8, giving an efficiency from 2.5 to 3.1 watts per mean hemispherical candle-power; showing an efficiency better than the incandescent but not so good as the arc lamp.

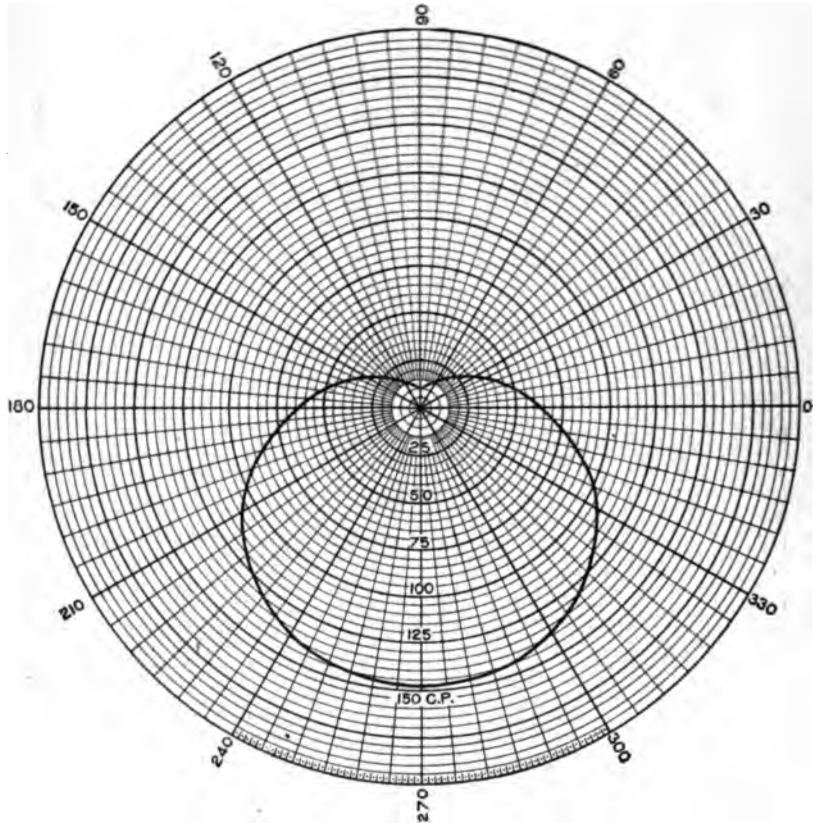

Fig. 25.

Fig. 25 shows two distribution curves for Nernst lamps.

To give the best results, lamps using the tube heaters must be cleaned regularly at intervals of about 100 hours of burning. The spiral heaters are not cleaned, but are renewed at the end of the useful life of the glower. The light given by these lamps is very white in color, and the use of sand-blasted or alabaster globes reduces its intense brilliancy.

Osmium Lamps. Osmium has been experimented on as a substance to replace carbon in the ordinary incandescent lamp, and so far very efficient lamps have been constructed using this material, but the voltage is low, due to the low resistance of the material and the difficulty of making a filament fine enough to give the desired resistance for higher voltages. At 25 volts, lamps are constructed giving an efficiency of 1.5 to 1.7 watts per candle-power, and with a life comparable with that of a 3.5-watt incandescent lamp. The low voltage makes this lamp undesirable for parallel distribution systems.

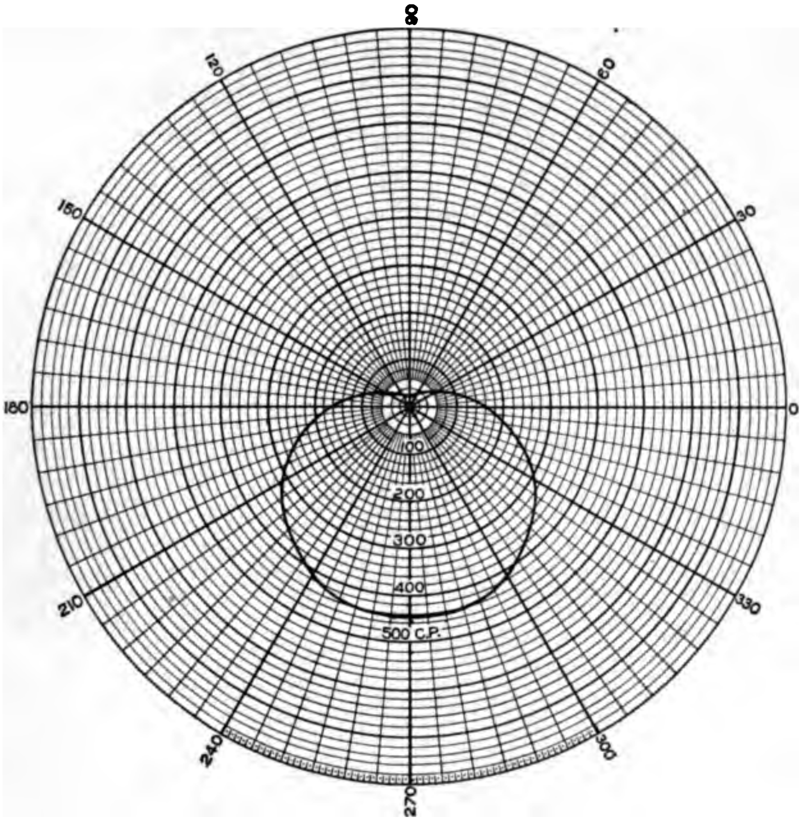

Fig. 25.

The Bremer Arc Lamp is one of the most favorable of several modifications of the arcs which have been proposed. This lamp uses very slender carbons having a core made of refractory oxides such as silica, lime, or magnesia. An efficiency of .1 to .4 watts per candle-power (mean spherical) has been claimed for this type of lamp, but it is still in the experimental stage.

The Mercury Vapor Lamp. Probably the Cooper Hewitt, or Mercury Vapor Lamp, is the only other special lamp deserving mention here. This lamp is being introduced to quite an extent where the quality of the light is not of so much importance. In this lamp, mercury vapor, rendered incandescent by the passage of an electric current, forms the source of light. One electrode is formed of mercury and the other may be of mercury or iron. In the more common type of lamp, these electrodes are mounted at the end of a long glass tube which has been very carefully exhausted. Fig. 26 shows such a lamp constructed for a 110-volt circuit. Dimensions of this lamp are as follows:

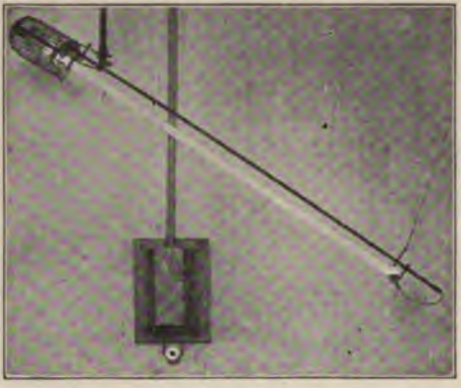
Fig. 26.

	For 100 Volts.	For 120 Volts.
Length of light-giving tube.......	43 inches.	49 inches.
Length over all..................	50 inches.	56 inches.
Diameter	1 inch.	

Current 3 to 3.5 amperes.
Candle Power at 120 volts, 750.
Life (average), 1,600 hours.

The mercury vapor, at the start, may be formed in two ways. First, the lamp may be tipped so that a stream of mercury makes contact between the two electrodes and mercury is vaporized when the stream breaks. Second, by means of a high inductance and a quick break switch; a very high voltage, sufficient to pass current from one electrode to the other, is induced and the conducting vapor formed. The lamp, as now manufactured, will operate only on direct current, but the alternating-current lamp is being developed.

Fig 27 is a diagram of a lamp connected for starting by the quick-break method, while Fig. 28 shows two 55-volt lamps connected in series on a 110-volt circuit, and arranged to be started by tipping. A steadying resistance and reactance are connected as shown in the diagram, the two being mounted on one base which may readily be attached to the wall as shown in Fig. 26.

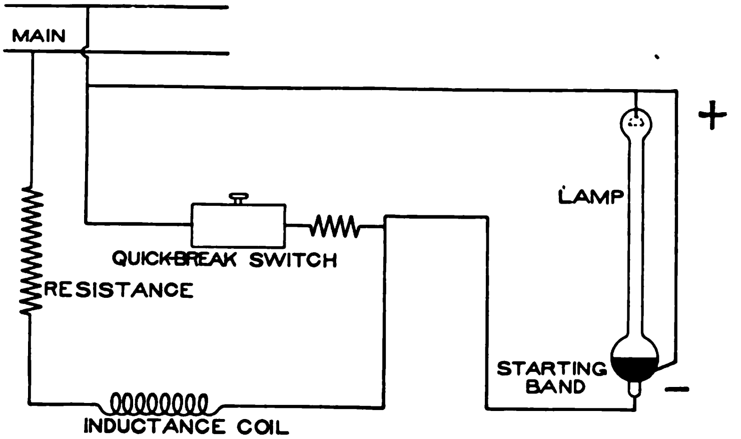

Fig. 27.

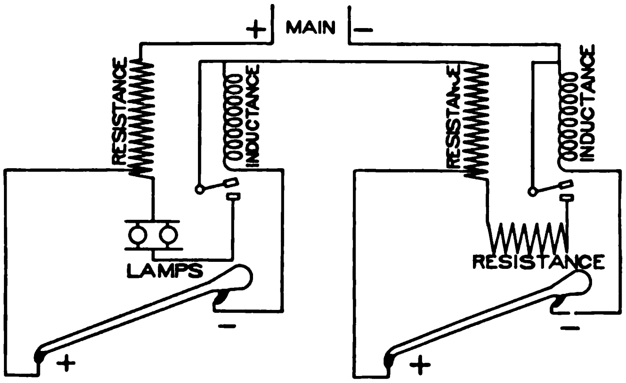

Fig. 28.

The mercury vapor lamp is not made in small sizes for ordinary voltages, and its light is very objectionable for the purpose of distinguishing color, as there is an entire absence of red rays.

This absence of the red light makes the illumination one that is very easy on the eyes but, on account of the color, its use is limited to the lighting of shops, offices, and drafting rooms, or in display windows where the goods shown are not changed in appearance by its color. It is also coming into use to a large extent in photographic work on account of the actinic properties of its light.

POWER DISTRIBUTION.

The question of power distribution for electric lamps and other appliances is taken up fully in the section on that subject, therefore it will be treated very briefly here. The systems may be divided into:

1. Series Distribution Systems.
2. Multiple-Series or Series-Multiple Systems.
3. Multiple or Parallel Systems.

They apply to both alternating and direct current.

The Series System is the most simple of the three; the lamps, as the name indicates, being connected in series as shown in Fig. 29. A constant load is necessary if a constant potential is to be used. If the load is variable, a constant-current generator, forms of which are described in "Types of Dynamo-Electric Machinery", or a special regulating device is necessary. Such devices are constant-current transformers and constant-current regulators as applied to alternating-current circuits.

The series system is used mostly for arc and incandescent lamps when applied to street illumination. Its advantages are simplicity and saving of copper. Its disadvantages are high voltage, fixed by the number of lamps in series; size of machines is limited since they cannot be insulated for voltage above about 6,000; a single open circuit shuts down the whole system.

Alternating-current series distribution systems are being used to a very large extent. By the aid of special transformers, or regulators, any number of circuits can be run from one machine or set of bus bars, and apparatus can be built for any voltage and of any size. It is not customary, however, to build transformers of this type having a capacity greater than 100, 6.6-ampere lamps.

The constant-current transformer most in use for lighting purposes is the one manufactured by the General Electric Company

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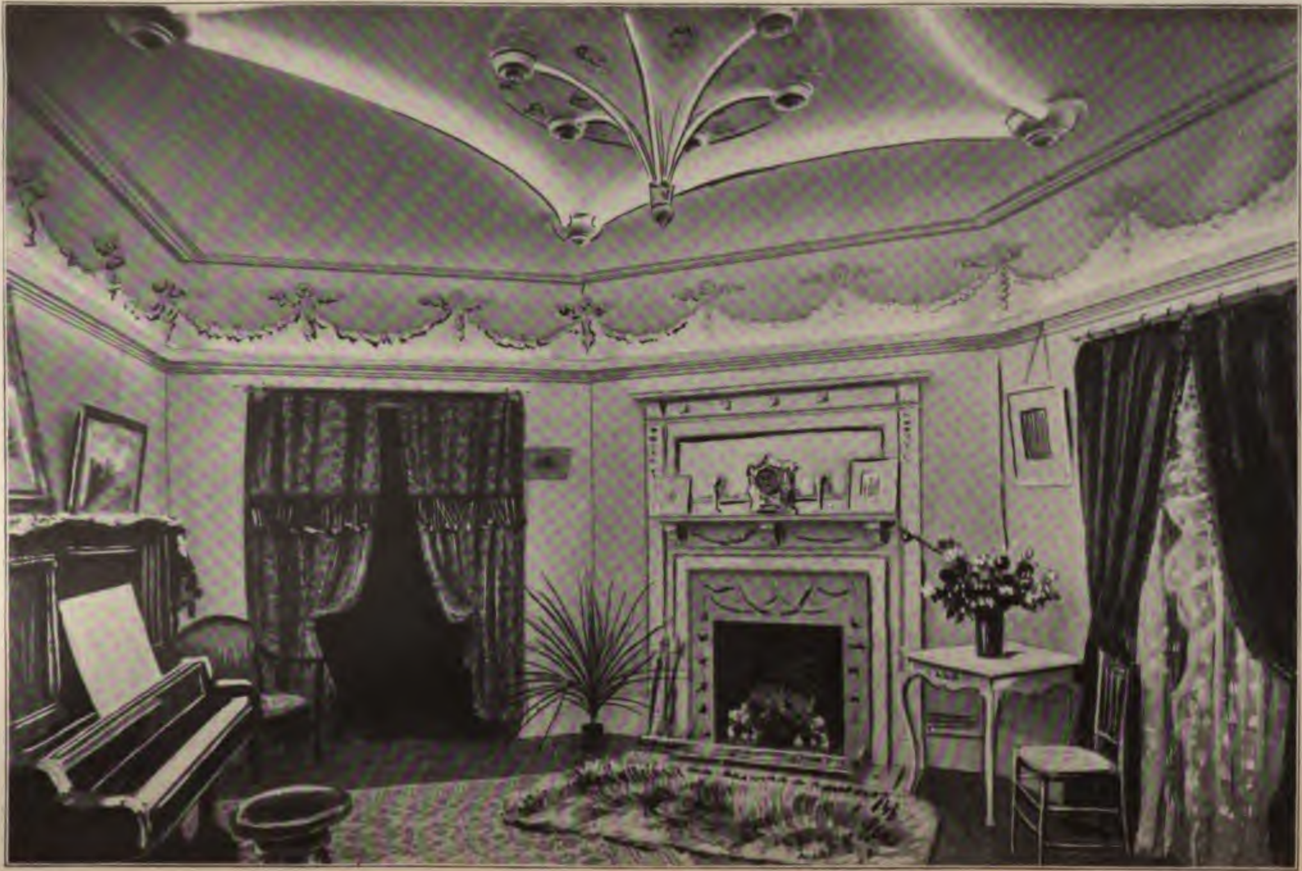


MOORE VACUUM-TUBE LIGHT.

Designed to Actually Imitate Daylight with a Better Efficiency than the Incandescent Lamp.

and commonly known as a "tub" transformer. Fig. 30 shows such a transformer when removed from the case, and Fig. 29 gives a diagram of the connection of a single-coil transformer in service.

Referring to Fig. 30, the fixed coils A form the primaries which are connected across the line; the movable coils B are the secondaries connected to the lamps. There is a repulsion of the coils B by the coils A when the current flows in both circuits and this force is balanced by means of the weights at W, so that the coils B take a position such that the normal current will flow in the secondary. On light loads, a low voltage is sufficient, hence the secondary coils are close together near the middle of the machine and there is a heavy magnetic leakage. When all of the lamps are on, the coils take the position shown when the leakage is a minimum and the voltage a maximum. When first starting up, the transformer is short-circuited and the secondary coils brought close together. The short circuit is then removed and the coils take a position corresponding to the load on the line.

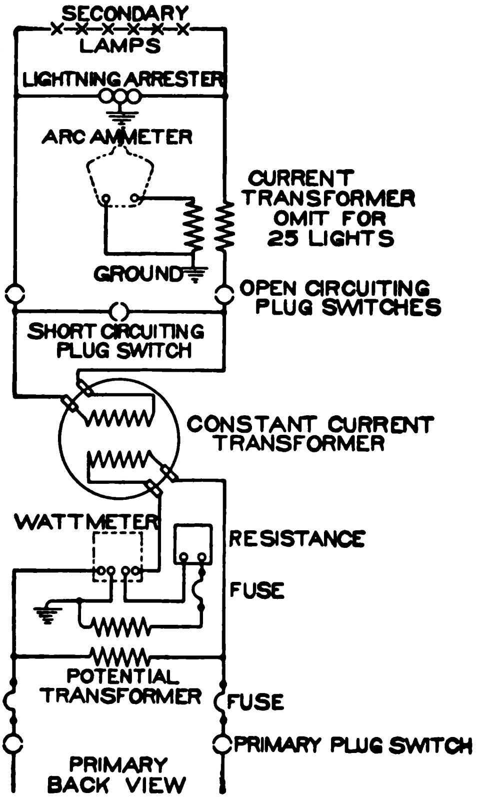


Fig. 29.

These transformers regulate from full load to $\frac{1}{3}$ rated load within $\frac{1}{10}$ ampere of normal current, and can be run on short circuit for several hours without overheating. The efficiency is given as 96% for 100-light transformers and 94.6% for 50-light transformers at full load. The power factor of the system is from

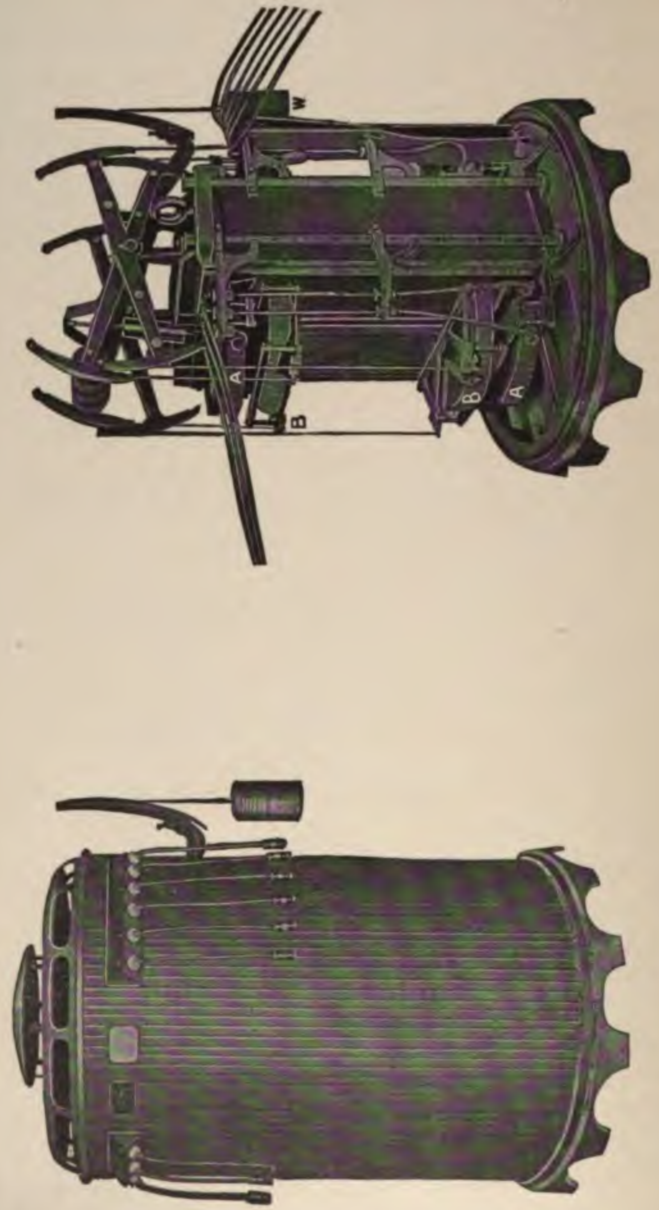


Fig. 30.

76 to 78% on full load, and, owing to the great amount of magnetic leakage at less than full load, the effect of leakage being the same as the effect of an inductance in the primary, the power factor is greatly reduced, falling to 62% at ¾ load, 44% at ½ load, and 24% at ¼ load.

Standard sizes are for capacities of 25, 35, 50, 75, and 100, 6.6 ampere enclosed arcs. The low power factor of such a system on light loads shows that a transformer should be selected of such a capacity that it will be fully or nearly fully loaded at all times. The primary winding can be constructed for any voltage and the open circuit voltages of the secondaries are as follows:

25	light transformer,	2300	volts.
35	" "	3200	"
50	" "	4600	"
75	" "	6900	"
100	" "	9200	"

The 50-, 75-, and 100-light transformers are arranged for multiple circuit operation, two circuits used in multiple, and the voltages at full load reach 4,100 for each circuit on the 100-light machine.

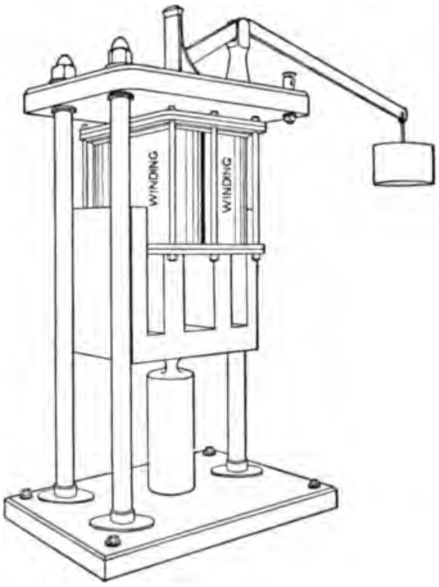


Fig. 31.

The second system, used for series distribution on alternating-current circuits, consists of a constant-potential transformer, stepping down the line voltage to that required for the total number of lamps on the system, allowing 83 volts for each lamp, and in series with the lamps is a reactive coil, the reactance of which is automatically regulated, as the load is increased or decreased, in order to keep the current in the line constant. Fig. 31 shows such a regulator as manufactured by the General Incandescent Arc Light Company, and Fig. 32 shows this regulator connected in circuit. The inductance is varied by the movement of the coil to include more or less iron in the magnetic circuit. Since the inductance in series with the lamps is high on light loads, the power factor is greatly reduced as in the constant-current transformer; and the circuits should, preferably, be run fully loaded. 60 to 65 lamps on a circuit is the maximum limit.

While used primarily for arc-light circuits, the same systems, designed for lower currents, are very readily applied to series incandescent systems.

Multiple-series and series-multiple systems combine several lamps in series and these groups in multiple, or several lamps in multiple and these groups in series, respectively. They have but a limited application.

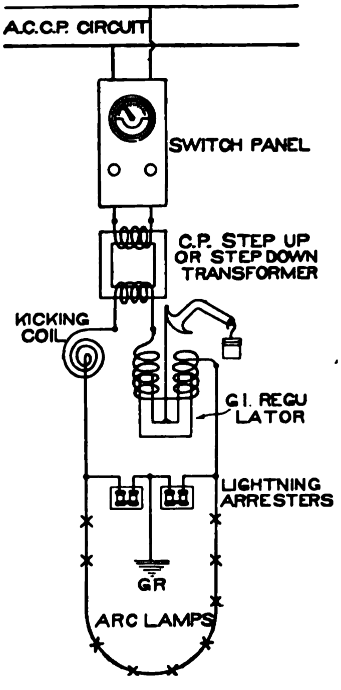


Fig. 32.

Multiple or Parallel Systems of Distribution. By far the largest number of lamps in service are connected to parallel systems of distribution. In this system, the units are connected across the lines leading to the bus bars at the station, or to the secondaries of constant-potential transformers. Fig. 33 shows a diagram of ten lamps connected in parallel. The current delivered by the machine depends directly on the number of lamps connected in service, the voltage of the system being kept constant.

Inasmuch as the flow of current in a conductor is always accompanied by a fall of potential equal to the product of the current flowing, into the resistance of the conductor, the lamps at the end of the system shown will not have as high a voltage impressed upon them as those nearer the machine. This drop in potential is the most serious obstacle that we have to overcome in multiple systems, and various schemes have been adopted to aid in this regulation. The systems may be classified as:

First, Cylindrical Conductors, parallel feeding.
Second, Conical " " "
Third, Cylindrical " anti-parallel feeding.
Fourth, Conical " " "

In the cylindrical conductor, parallel-feeding system, the conductors, A, B, C, D, Fig. 33, are of the same size throughout and are fed at the same end by the generator. The voltage is a minimum at the lamps E and a maximum at the lamps F; the value of the voltage at any lamp being readily calculated.

By a conical or tapering conductor is meant a conductor whose diameter is so proportioned throughout its length that the current, divided by the cross-section or the current density, is a constant quantity. Such a conductor is approximated in practice by using smaller sizes of wire as the current in the lines becomes less.

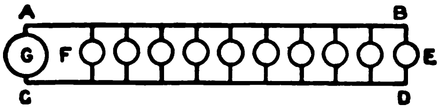


Fig. 33.

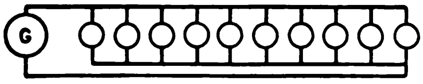


Fig. 34.

In an anti-parallel system, the current is fed to the lamps from opposite ends of the system as shown in Fig. 34.

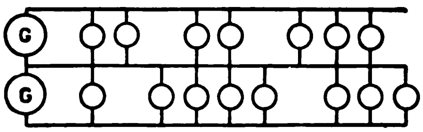


Fig. 35.

Multiple-Wire Systems. In order to take advantage of a higher voltage for distribution of power to the lighting circuits, three- and five-wire systems have been introduced, the three-wire system being used to a very large extent. In this system, three conductors are used, the voltage from each outside conductor and the middle neutral conductor being the same as for a simple parallel system. Fig. 35 gives a diagram of this. By this system the amount of copper required for a given number of lamps is from five-sixteenths to three-eighths of the amount required for a two-wire distribution, depending on the size of the neutral conductor. The saving of copper together with the disadvantages of the system is more fully treated in the paper on Power Transmission.

ILLUMINATION.

Illumination may be defined as the quality and quantity of light which aids in the discrimination of outline and the perception of color. Not only the quantity, but the quality of the light, as well as the arrangement of the units, must be considered in a complete study of the subject of illumination.

The Unit of Illumination is the *candle-foot* and its value is the amount of light falling on a surface at a distance of one foot from a source of light one candle-power in value. The law of inverse squares, namely, that the illumination from a given source varies inversely as the square of the distance from the source, shows that the illumination at a distance of two feet from a single candle-power unit is .25 candle-foot. For further consideration of the law of inverse squares, see " Photometry ".

Illumination may be classified as *useful* illumination, when used for the ordinary purposes of furnishing light for carrying on work, taking the place of daylight, and *scenic* illumination. The latter applies to all forms of decorative lighting such as stage lighting, etc. The two divisions are not, as a rule, distinct, but the one is combined with the other.

Intrinsic Brightness. By intrinsic brightness is meant the amount of light emitted per unit surface of the light source. Table 3 gives the intrinsic brightness of several light sources.

TABLE 3.

Intrinsic Brilliancies in Candle-Power per Square Inch.

Source	Brilliancy	Notes.
Sun in zenith	600,000	Rough equivalent values, taking account of absorption.
Sun at 30 degrees elev.	500,000	
Sun on horizon	2,000	
Arc light	10,000 to 100,000	Maximum about 200,000 in crater.
Calcium light	5,000	
Nernst "glower"	1,000	Unshaded.
Incandescent lamp	200–300	Depending on efficiency.
Enclosed arc	75–100	Opalescent inner globe.
Acetylene flame	75–100	
Welsbach light	20 to 25	
Kerosene light	4 to 8	Variable.
Candle	3 to 4	
Gas flame	3 to 8	Variable.
Incandescent (frosted)	2 to 5	
Opal shaded lamps, etc.	0.5 to 2	

Regular Reflection. Regular reflection is the term applied to reflection of light when the reflected rays are parallel. It is of such a nature that the image of the light source is seen in the reflection. The reflection from a plane mirror is an example of this. It is useful in lighting in that the direction of light may be changed without complicating calculations aside from deductions necessary to compensate for the small amount of light absorbed.

Irregular Reflection, or diffusion, consists of reflection in which the reflected rays of light are not parallel but take various directions, thus destroying the image of the light source. Rough, unpolished surfaces give such reflection. Smooth, unpolished surfaces generally give a combination of the two kinds of reflection. Diffused reflection is very important in the study of illumination inasmuch as diffused light plays an important part in the lighting of interiors. This form of reflection is seen in many photometer screens. Light is also diffused when passing through semi-transparent shades or screens.

In considering reflected light, we find that, if the surface on which the light falls is colored, the reflected light may be changed in its nature by the absorption of some of the colors. Since, as has been said, in interior lighting the reflected light forms a large part of the source of illumination, this illumination will depend upon the nature and color of the reflecting surfaces.

Whenever light is reflected from a surface, either by direct or diffused reflection, a certain amount of light is absorbed by the surface. Table 4 gives the amount of white light reflected from different materials.

TABLE 4.

Material.	
White blotting paper	.82
White cartridge paper	.80
Chrome yellow paper	.62
Orange paper	.50
Yellow wall paper	.40
Light pink paper	.36
Yellow cardboard	.30
Light blue cardboard	.25
Emerald green paper	.18
Dark brown paper	.13
Vermilion paper	.12
Blue-green paper	.12
Black paper	.05
Black cloth	.012
Black velvet	.004

From this table it is seen that the light-colored papers reflect the light well, but of the darker colors only yellow has a comparatively high coefficient of reflection. Black velvet has the lowest value, but this only holds when the material is free from dust. Rooms with dark walls require a greater amount of illuminating power, as will be seen later.

Useful illumination may be considered under the following heads:

1. Residence Lighting.
2. Lighting of Public Halls, Offices, Drafting Rooms, Shops, etc.
3. Street Lighting.

RESIDENCE LIGHTING.

Type of Lamps. The lamps used for this class of lighting are limited to the less powerful units, namely, incandescent or Nernst lamps varying in candle-power from 8 to 32 per unit. These should always be shaded so as to keep the intrinsic brightness low. The intrinsic brilliancy should seldom exceed 2 to 3 candle-power per square inch, and its reduction is usually accomplished by appropriate shading. Arc lights are so powerful as to be uneconomical for small rooms, while the color of the mercury-vapor light is an additional objection to its use.

Plan of Illumination. Lamps may be selected and so located as to give a brilliant and fairly uniform illumination in a room; but this is an uneconomical scheme, and the one more commonly employed is to furnish a uniform, though comparatively weak, ground illumination, and to reinforce this at points where it is necessary or desirable. The latter plan is satisfactory in almost all cases and the more economical of the two.

While the use of units of different power is to be recommended, where desirable, lights differing in color should not be used for lighting the same room. As an exaggerated case, the use of arc with incandescent lamps might be mentioned. The arcs being so much whiter than the incandescent lamps, the latter appear distinctly yellow when the two are viewed at the same time.

Calculation of Illumination. In determining the value of illumination, not only the candle-power of the units, but the amount of reflected light must be considered for the given location of the lamps. Following is a formula based on the coefficient of reflection of the walls of the room, which serves for preliminary calculations:

$$I = \frac{c.p.\ \frac{1}{1-k}}{d^2}$$

I = Illumination in candle-feet.

$c.p.$ = Candle-power of the unit.

k = Coefficient of reflection of the walls.

d = distance from the unit in feet.

Where several units of the same candle-power are used this formula becomes

$$I = c.p.\left(\frac{1}{d^2} + \frac{1}{d^2_1} + \frac{1}{d^2_2} + \text{---------}\right)\frac{1}{1-k}$$

or,

$$c.p. = \frac{I}{\left(\frac{1}{d^2} + \frac{1}{d^2_1} + \frac{1}{d^2_2} + \text{---------}\right)\frac{1}{1-k}}$$

where d, d_1, d_2, etc., equal the distances from the point considered to the various light sources. If the lamps are of different candle-power, the illumination may be determined by combining the illumination from each source as calculated separately. An example of calculation is given under "Arrangement of Lamps".

It is readily seen that the effect of reflected light from the ceilings is of more importance than that from the floor of a room. The value of k, in the above formula, will vary from 60% to 10%, but for rooms with a fairly light finish 50% may be taken as a good average value.

The amount of illumination will depend on the use to be made of the room. One candle-foot gives sufficient illumination for easy reading, when measured normal to the page, and probably an illumination of .5 candle-foot on a plane 3 feet from the floor forms a sufficient ground illumination. The illumination from sunlight reflected from white clouds is from 20 candle-feet up, while that due to moonlight is in the neighborhood of .03 candle-foot. It is not possible to produce artificially a light equivalent to daylight on account of the great amount of energy that would be required and the difficulty of obtaining proper diffusion.

Arrangement of Lamps. An arrangement of lamps giving a uniform illumination cannot be well applied to residences on account of the number of units required, and the inartistic effect. We are limited to chandeliers, side lights, or ceiling lights, in the majority of cases, with table or reading lamps for special illumination.

When ceiling lamps are used and the ceilings are high, some form of reflector or reflector lamp is to be recommended. In any case where the coefficient of reflection of the ceilings is less than 40%, it is more economical to use reflectors. When lamps are mounted on chandeliers, the illumination is far from uniform, being a maximum in the neighborhood of the chandelier and a minimum at the corners of the room. By combining chandeliers with side lights it is generally possible to get a satisfactory arrangement of lighting for small or medium-sized rooms.

As a check on the candle-power in lamps required, we have the following:

For brilliant illumination allow one candle-power per two square feet of floor space. In some particular cases, such as ball rooms, this may be increased to one candle-power per square foot.

For general illumination allow one candle-power for four square feet of floor space, and strengthen this illumination with the aid of special lamps as required. The location of lamps and the height of ceilings will modify these figures to some extent.

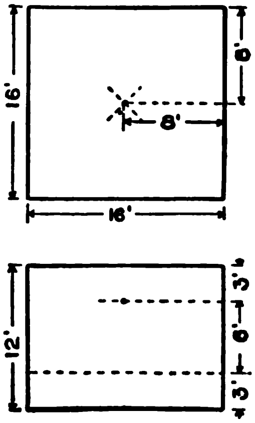


Fig. 36.

As an example of the calculation of the illumination of a room with different arrangements of the units of light, assume a room 16 feet square, 12 feet high, and with walls having a coefficient of reflection of 50%. Consider first the illumination on a plane 3 feet above the floor when lighted by a single group of lights mounted at the center of the room 3 feet below the ceiling. If a minimum value of .5 candle-foot is required at the corner of the room we have the equation

$$.5 = c.p.\frac{1}{12.8^2} \times \frac{1}{1-.5}$$

Since $d = \sqrt{8^2 + 8^2 + 6^2} = 12.8$ (see Fig. 36)

Solving the above for the value of *c.p.*, we have

$$c.p. = \frac{.5}{\frac{1}{164} \times \frac{1}{.5}} = .5 \times 82 = 41$$

Three 16-candle-power lamps would serve this purpose very well.

Determining the illumination directly under the lamp, we have:

$$I = 48 \times \frac{1}{6^2} \times \frac{1}{1-.5} = \frac{48}{36} \times 2 =$$

2.7 candle-feet, or five times the value of the illumination at the corners of the room.

Next consider four 8-candle-power lamps located on the side walls 8 feet above the floor as shown in Fig. 37. Calculating the illumination at the center of the room on a plane three feet above the floor, we have:

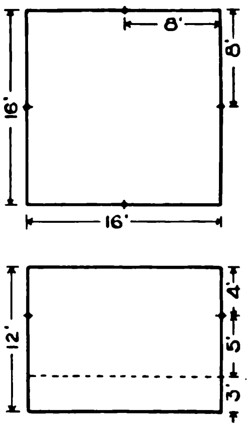


Fig. 37.

$$I = 8(\frac{1}{89} + \frac{1}{89} + \frac{1}{89} + \frac{1}{89})\frac{1}{1-.5}$$

$$d^2 = 8^2 + 5^2 = 64 + 25 = 89$$

$$I = 8 \times \frac{4}{89} \times 2 = .72 \text{ candle-foot.}$$

The illumination at the corner of the room would be:

$$I = 8(\frac{1}{89} + \frac{1}{89} + \frac{1}{345} + \frac{1}{345})\frac{1}{1-.5}$$

$$= 8(\frac{2}{89} + \frac{2}{345}) \times 2 = .45 \text{ candle-foot.}$$

In a similar manner the illumination may be calculated for any point in the room, or a series of points may be taken and curves plotted showing the distribution of the light, as well as the areas having the same illumination. Where refined calculations are desired, the distribution curve of the lamp must be used for deter-

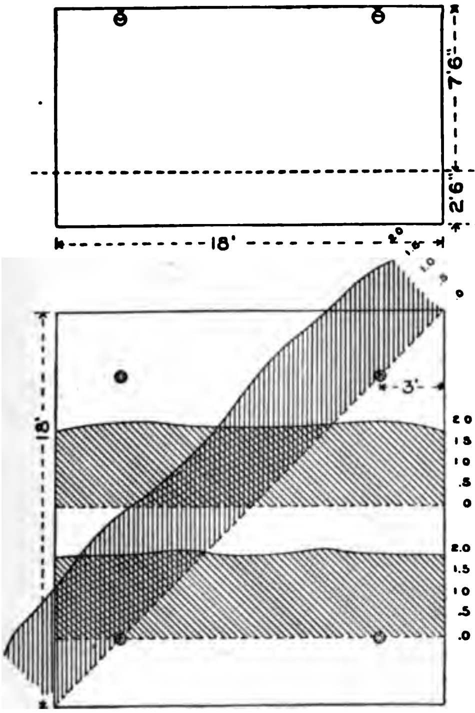


Fig. 38.

mining the candle-power in different directions. Fig. 38 shows illumination curves for the Meridian lamp manufactured by the General Electric Company. This is a form of reflector lamp made in two sizes, 25 or 50 candle-power. Fig. 39 gives the distribution curves for the 50-candle-power unit. Similar incandescent lamps are now being manufactured by other companies.

Table 5 gives desirable data in connection with the use of the Meridian lamp.

By means of the Weber, or some other form of portable photometer, curves as plotted from calculations may be readily checked after the lamps are installed. When lamps are to be permanently located, the question of illumination becomes an

TABLE 5.

Illuminating Data for Meridian Lamps.

Class Service.	Light Intensity in Candle-feet.	No. 1 Lamp (60 Watts)		No. 2 Lamp (120 Watts)		Watts per Sq. Ft. of Area Lighted With Either Lamp.
		Height of Lamp and Diameter of Uniformly Lighted Area.	Distance Between Lamps When Two or More are Used.	Height of Lamp and Diameter of Uniformly Lighted Area.	Distance Between Lamps When Two or More are Used.	
Desk or Reading Table.	3	2.9 feet.	4.9 feet.	4 feet.	7 feet.	2.50
	2	3.5 "	6 "	5 "	8.5 "	1.66
	1½	4 "	7 "	5.75 "	9.8 "	1.25
General Lighting.	1	5 "	8.5 "	7 "	12 "	0.83
	¾	5.75 "	9.8 "	8.2 "	13.9 "	0.62
	½	7 "	12 "	10 "	11 "	0.41

important one, and it is customary to determine, by calculation, the illumination curves and the isophotals, Fig. 38, as the lines showing equal illumination are called, for each room before installing the lamps. This applies to the lighting of large interiors more particularly than to residence lighting.

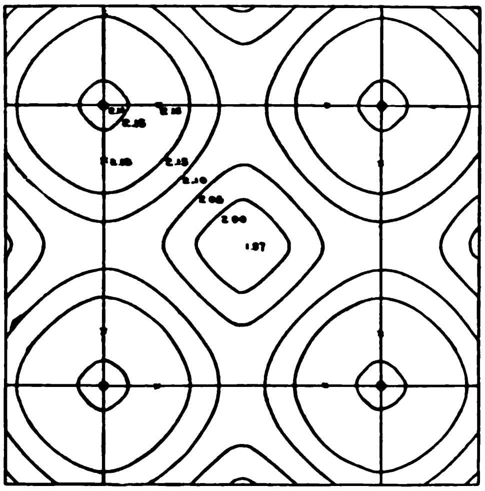


Fig. 38.

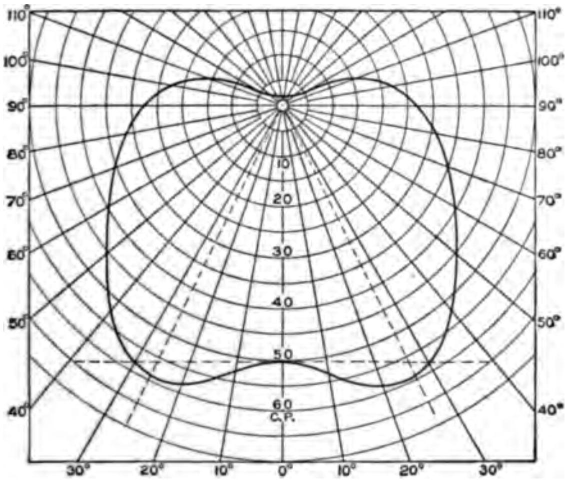


Fig. 39.

Dr. Louis Bell gives the following in connection with residence lighting:

TABLE 6.

Room.	8 c.p.	16 c.p.	32 c.p.	Sq. ft. per c.p.	Remarks.
Hall, 15′ × 20′	8			4.7	
Library, 20′ × 20′	12		1	3.1	8-c.p. reflector lamps.
Reception room, 15′ × 15′	4			7.0	
Music room, 20′ × 25′	12		2	3.0	
Dining room, 15′ × 20′	14			2.7	8 reflect'r lamps
Billiard room, 15′ × 20′			4	2.3	32-c.p. with reflectors.
Porch			1		
Bedrooms (6), 15′ × 15′		14		7.0	
Dressing rooms (2), 10′ × 15′		4		4.7	
Servants' rooms (3), 10′ × 15′		3		9.4	
Bathrooms (3), 8′ × 10′		3		5.0	
Kitchen, 15′ × 15′ Pantry, 10′ × 15′		3			
Halls Cellar	10	3			
Closets (4)	4				Reflector lamps
Total	64	30	8		

LIGHTING OF PUBLIC HALLS, OFFICES, ETC.

Lighting of public halls and other large interiors differs from the illumination of residences in that there is usually less reflected light, and, again, the distance of the light sources from the plane of illumination is generally greater if an artistic arrangement of the lights is to be brought about. This in turn reduces the direct illumination. The primary object is, however, as in residence lighting, to produce a fairly uniform ground illumination and to superimpose a stronger illumination where necessary. An illlumination of .5 candle-feet for the ground illumination may be taken as a minimum.

In the lighting of large rooms it is permissible to use larger light units, such as arc lamps and high candle-power Nernst or incandescent units, while for factory lighting and drafting rooms, where the color of the light is not so essential, the Cooper Hewitt lamp is being introduced. High candle-power reflector lamps, such as the Meridian lamp, are being used to a large extent for offices and drafting rooms.

The choice of the type of lamp depends on the nature of the work. Where the light must be steady, incandescent or Nernst lamps are to be preferred to the arc or vapor lamps, though the latter are often the more efficient. When arcs are used, they must be carefully shaded so as to diffuse the light, doing away with the strong shadows due to portions of the lamp mechanism, and to reduce the intrinsic brightness. Such shading will be taken up under the heading "Shades and Reflectors". Arcs are preferable to incandescent lamps when colored objects are to be illuminated, as in stores and display windows.

In locating lamps for this class of lighting, much depends on the nature of the building and on the degree of economy to be observed. For preliminary determination of the location of groups, or the illumination when certain arrangement of the units is assumed, the principles outlined under "Residence Lighting" may be applied. It has been found that actual measurements show results approximating closely such calculated values.

When arcs are used they should be placed fairly high, twenty to twenty-five feet when used for general illumination and the ceilings are high. They should be supplied with reflectors so as to utilize the light ordinarily thrown upwards. When used for drafting-room work, they should be suspended from twelve to fifteen feet above the floor, and special care must be taken to diffuse the light.

Incandescent lamps may be arranged in groups, either as side lights or mounted on chandeliers, or they may be arranged as a frieze running around the room a few feet below the ceiling. The last named arrangement of lights is one that may be made artistic, but it is uneconomical and when used should serve for the ground illumination only. Reflector lights may be used for this style of work and the lights may be entirely concealed from view, the reflecting property of the walls being utilized for distributing the light where needed.

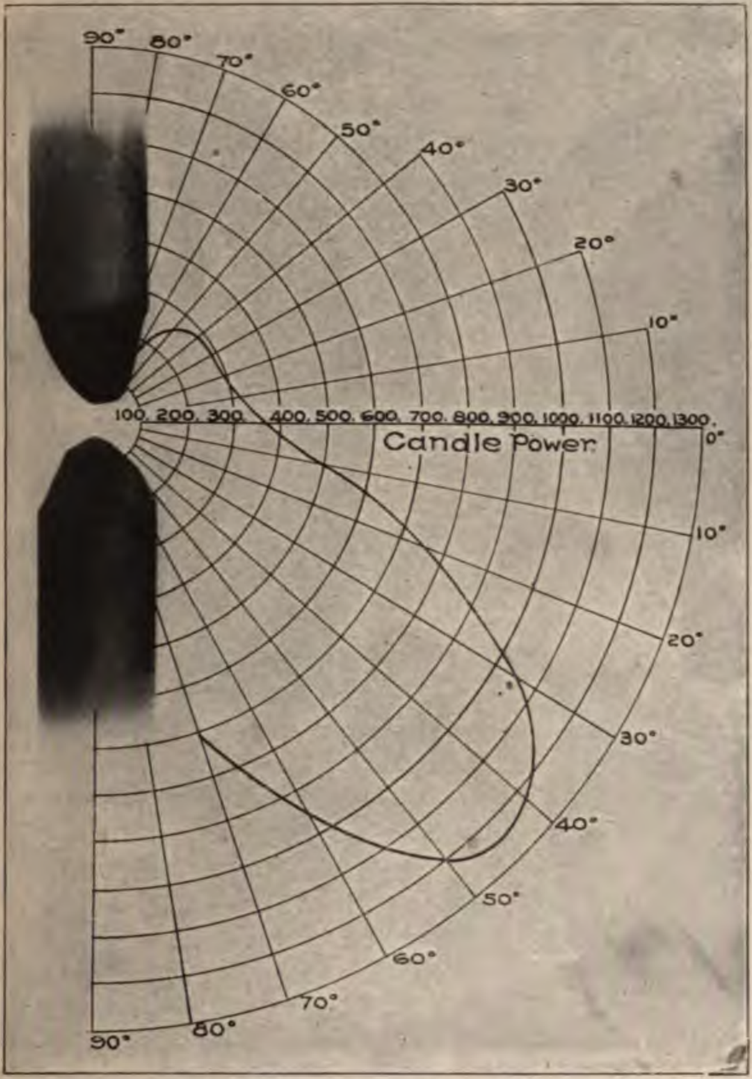
Ceiling lights should preferably be supplied with reflectors, especially when the ceilings are high.

Measurements taken in well-lighted rooms having a floor space of from 1,000 to 5,000 square feet show an average of 3 to 3.5 square feet per candle-power. About 2.5 square feet per candle-power should be allowed when brilliant lighting is required or the ceilings are very high, while 3.75 square feet per candle power

TABLE 7.

Lighting Data for Arc Lamps.

Place Lighted.	Clothing Store.	Weave Room.	Erecting Room.	Machine Shop.	Drafting Room.	Drafting Room.	Ship Shed.	Cataloging Dept.	Jewelry Store.
No. of sq. ft. place lighted	4000	14400	281600	42250	6275	5690	69000	4136	4000
No. lamps used	12	50	200	42	27	24	50	17	6
Circuit	A. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult.	A. C. Series.	D. C. Mult.	*D. C. Mult.	D. C. Mult.	D. C. Mult.
Cycles	60	......	......	......	60	......	......	......	......
Volts line	104	110	120	120	......	120	220	110	110
Amperes	6	3¼	6.2	6.2	7.5	4	6	4½	5
Volts at arc	72	75	80	80	72	80	80	80	80
Power factor of lamp	.69	......	......	......	.86	......	......	......	......
Watts per lamp	430	357	744	744	490	480	660	495	550
Watts per sq. ft. (term.)	1.29	1.24	.53	.74	2.11	2.02	.478	2.03	.825
Kw. at term. (whole installation)	5.16	17.8	148.8	31.25	13.22	11.52	33	8.42	3.3
Kw. at arc (whole installation)	4.62	12.28	99.2	20.8	12.42	7.68	24	6.12	2.4
Sq. ft. lighted per lamp	333	288	1408	1006	232	237	1380	243	667
Sq. ft. lighted per amp	55.6	88.6	227	162	31	59.2	230	54.1	133.5
Enclosing globe	Opal		Opal.	Opal.	Opal.	Opal.		Opal.	Opal.
Height and style of ceiling	12′ white steel.	Saw Toothed.	Trussed.	Trussed.	12′ White.	Trussed.	160′ Trussed.	13′ 9″ Maroon.	16′ 10′ White.
Reflector system used	Concentric Diffuser.	Adjust. Diffuser.	9″ Mirror.	9″ Mirror.	Concentric Diffuser.	16 Adj. Dif. 8 Con. Dif.	12″ Mirror.	Concentric Diffuser.	Concentric Diffuser.
Height of arc from floor	9′ 6″	12′ to 15′	46′	47′	9′	15′	150′	10′ 7″	13′ 2″
Distance between lamps	14′ to 18′	24′	33′ to 38′	30′ 9″	15′	12′ to 25′	17′ to 20′	14′ to 18′	16′ to 35′



DISTRIBUTION CURVE FOR ARC LAMP.

Fort Wayne Electric Works.

RK
BRARY
ASTOR, LENOX
TILDEN FOUNDATIONS

will give good illumination when lights are well distributed and there is considerable reflected light.

In factory and drafting room lighting, the lamps must be arranged to give a strong light where most needed, and located to prevent such shadows as would interfere with the work.

Following are tables showing the number and distribution of arc and mercury-vapor lamps for lighting large rooms. Table 7 refers to arc lights as actually installed.

TABLE 8.

Lighting Data for Cooper-Hewitt Lamps.

Drafting Room.	2,140 sq. ft.	8 V-5 lamps.
	265 sq. ft. per lamp.	8 × 3.3 amperes = 26.5 amp.
	voltage 110.	80 sq. ft. per amp.
Office.	1,100 sq. ft.	3 H-4 lamps.
	366 sq. ft. per lamp.	3x3.3 amp. = 10 amp.
	voltage 110.	110 sq. ft. per amp.
Factory.	12,000 sq. ft.	30 V-4 lamps.
	400 sq. ft. per lamp.	30x1.7 amp. = 51 amp.
	voltage 110.	

STREET LIGHTING.

In studying the lighting of streets and parks, we find that, except in special cases, such as narrow streets and high buildings, there is no reflected light which aids the illumination aside from that due to special shades or reflectors on the lamp itself. Such reflectors are necessary if the light ordinarily thrown above the horizontal plane is to be utilized.

In calculating the illumination due to any type of lamp at a given point it is necessary to know the distribution curve of the lamp used and the distance to the point illuminated. The approximate illumination is given by the formula,

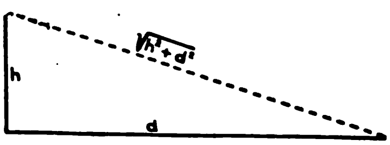


Fig. 40.

$$I = \frac{c.p.}{h^2 + d^2}$$

when I = illumination in candle-feet.

c.p. = candle-power of the unit, determined from the distribution curve of the lamp.

h = distance the lamp is mounted above the ground, in feet, and d = distance from the base of the pole supporting the lamp to the point where the illumination is being considered. See Fig. 40.

While this will give the illumination in candle-feet, the nature of the lighting cannot be decided from this alone, but the total amount of light must also be considered. Thus, a street lighted with powerful units and giving a minimum illumination of .05 candle-foot would be considered better illuminated than one having smaller units so distributed as to give the same minimum value.

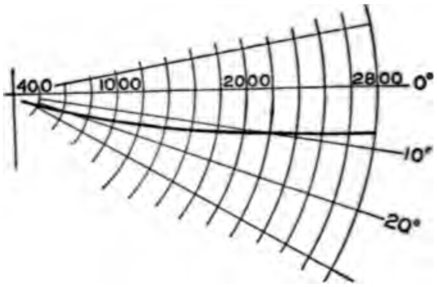


Fig. 41.

Since a uniform distribution of light is desirable, for economic reasons, the ideal distribution curve of a lamp for street lighting would be a curve which shows a low value of candle-power thrown directly downward, but with the candle-power increasing as we approach the horizontal. Such an ideal distribution curve is shown in Fig. 41.

Actual distribution curves taken from commercial arc lamps are given in Fig. 42, in which

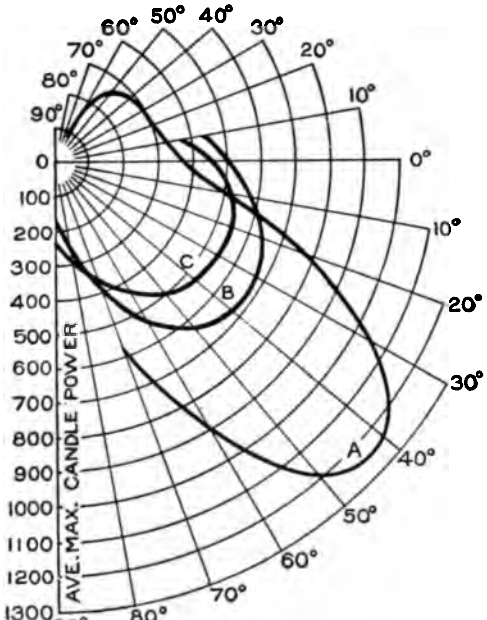


Fig. 42.

Curve A shows distribution curve for a 9.6-ampere, open, direct-current arc.

Curve B shows distribution curve for a 6.6 ampere, D.C. enclosed arc.

Curve C shows distribution curve for a 7.5-ampere, A.C. enclosed arc.
Globes used with B and C are opal, inner globes, clear, outer globes.
Globes used with A are clear outer globes.
A street reflector was used with the enclosed arcs.

A series of curves known as illumination curves may be readily calculated showing the illumination in candle-feet at given distance from the foot of the pole supporting the lamp. Illumination curves corresponding to the distribution curves in Fig. 42 are given in Fig. 43 where A′, B′, and C′ correspond to A, B, and

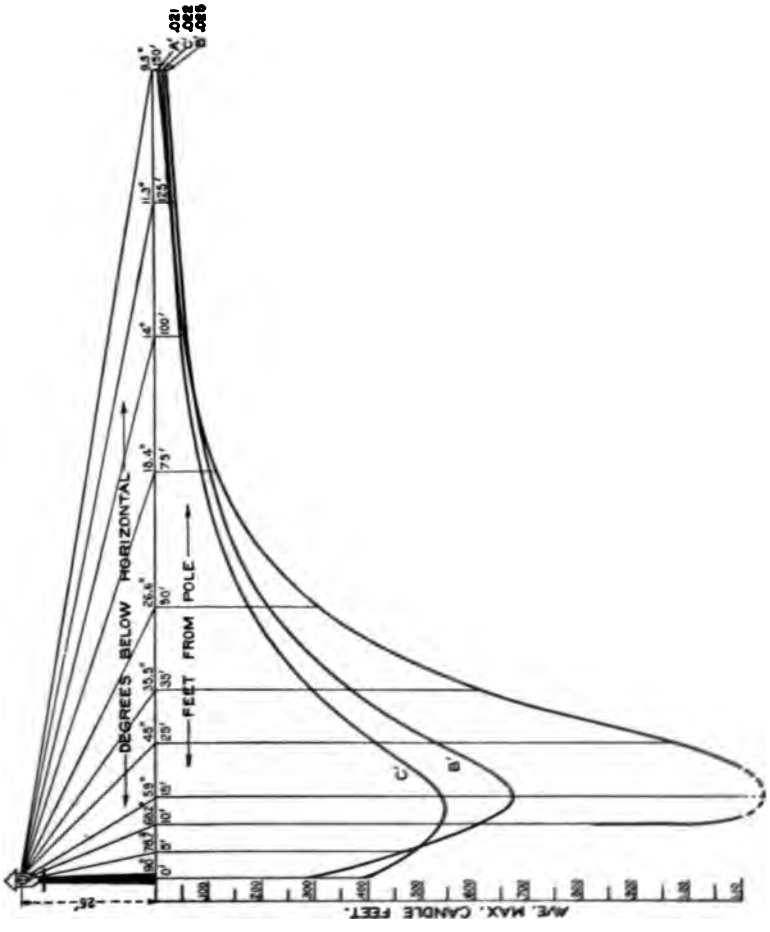


Fig. 43.

C in Fig. 42. These curves correspond to actual readings taken with commercial lamps. Similar curves for incandescent lamps are shown in Fig. 44. A value of .03 candle-foot is about the minimum for good street lighting. Open arcs should be placed at least 25 feet above the ground; 30 to 40 feet is better, especially if the space to be illuminated is quite open. With enclosed arcs it is often advantageous to place them as low as 18 to 20 feet from the ground. Table 9 gives the distance between lights for different types of arcs for good illumination.

TABLE 9.

Kind of Light.	Distance between Lights.	Lights Per Mile.
6.6-ampere enclosed D.C. arc............	340 Feet.	15
9.6-ampere open D.C. arc...............	315 "	17
6.6-ampere enclosed A.C. arc............	275 "	19
6.6-ampere open D.C. arc................	260 "	20

In considering the type of arc light to be used we must turn to the illumination curves as shown in Fig. 43. These curves show that the illumination from a direct-current open arc in its present form is superior to that from a direct-current enclosed arc, taking the same amount of power, in the vicinity of the pole, but at a distance of 100 feet, the illumination from the enclosed arc is better. This illumination is still more effective on account of the absence of such strong light as is given by the open arc near the pole. The pupil of the eye adjusts itself to correspond to the brightest light in the field of vision, and we are unable to see as well in the dimly-lighted section as when the maximum intensity is less. The characteristics of the open, direct-current arc lamps are as follows:

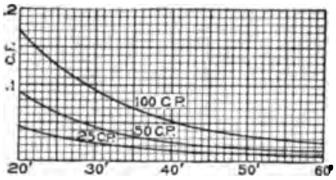


Fig. 44.

The mean spherical candle-power and energy required at the arc are variable.

Fluctuations of light are marked, due to wandering of the arc, flickering due to the wind and lack of uniformity of the carbons.

Dense shadows are cast by the side rods and the lower carbon, while the light is objectionably strong in the vicinity of the pole.

With the enclosed arc the mean spherical candle-power and the watts consumed at the arc are fairly constant.

No shadows are cast by the lamps, and the illumination is not subject to such wide variations. The enclosed arc is much superior to the open arc using the same amount of energy. This applies to the open arc as it is now used. With proper reflection and diffusion of the light such as might be accomplished by extensive or special shading, we ought to be able to get as good distribution from the open arc with a greater total amount of illumination.

In comparing the direct-current with the alternating-current enclosed arc, we see that the direct-current arc gives slightly more light than the alternating lamp, but this may be more than counterbalanced by the better distribution of light from the alternating-current lamp. The selection of A.C. or D.C. enclosed lamps will usually depend on other conditions, such as method of distribution of power, efficiency of plant, etc.

Series incandescent lamps are used considerably for lighting the streets in residence sections of cities or where shade trees make it impracticable to use arcs. These vary in candle-power from 16 to 50 or even higher, and are usually constructed so as to take from two to four amperes. The best arrangement of these is to mount them on brackets a few feet from the curb, with alternate lamps on opposite sides of the street. The distance between the lamps depends on their power. 50 candle-power lamps spaced 100 feet between lamps, give a minimum illumination of .02 candle-foot. 25 candle-power lamps spaced 75 feet between lamps will serve where economy is necessary.

SHADES AND REFLECTORS.

Lamps, as ordinarily constructed, do not always give a suitable distribution of light, while the intrinsic brightness is often too high for interior lighting. Shades are intended to modify the intensity of the light, while reflectors are used for the purpose of changing its direction. Frequently the two are combined in various ways. Shades are also used for decorative purposes, but, if possible, these should be of such a nature as to aid illumination rather than to reduce its efficiency.

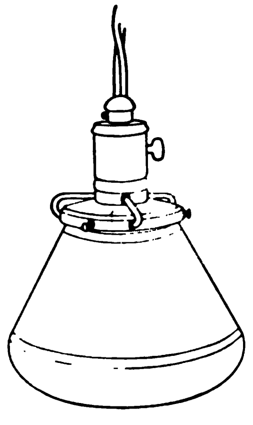


Fig. 45.

A considerable amount of light is absorbed by the material used for the construction of shades. Table 10 shows the approximate amount absorbed by some materials.

Of the great number of styles of shades and reflectors in use, only a few of the more important will be considered here.

TABLE 10.

	Per Cent
Clear glass	10
Alabaster glass	15
Opaline glass	20-40
Ground glass	25-30
Opal glass	25-60
Milky glass	30-60
Ground glass	24.4
Prismatic glass	20.7
Opal glass	32.2
Opaline glass	23.0

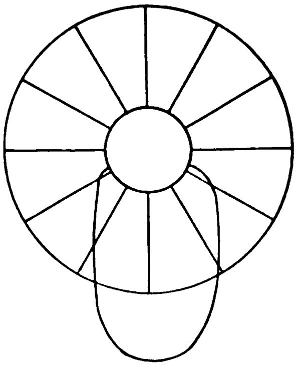


Fig. 46.

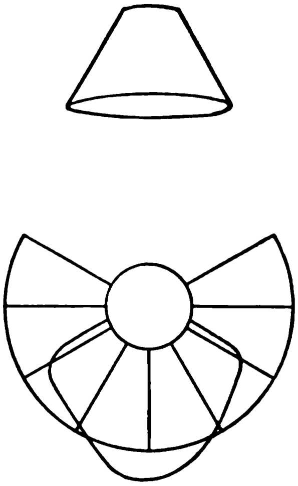


Fig. 47.

One of the simplest methods of shading incandescent lamps is by the use of "frosted" globes. These serve to reduce the intrinsic brightness of the lamp, and should be freely used for residence lighting when separate shades are not installed. Frosted globes are also used in connection with reflectors for the purpose of diffusing the reflected light. The McCreary shade as shown in

Fig. 45 is an example of such a combined shade and reflector. Fig. 46 shows the distribution curve taken from an incandescent lamp using a McCreary shade. Fig. 47 shows the distribution of light from a conical shade. Fig. 39 shows the distribution of light brought about by means of a spiral filament and a reflector as used in the Meridian lamp.

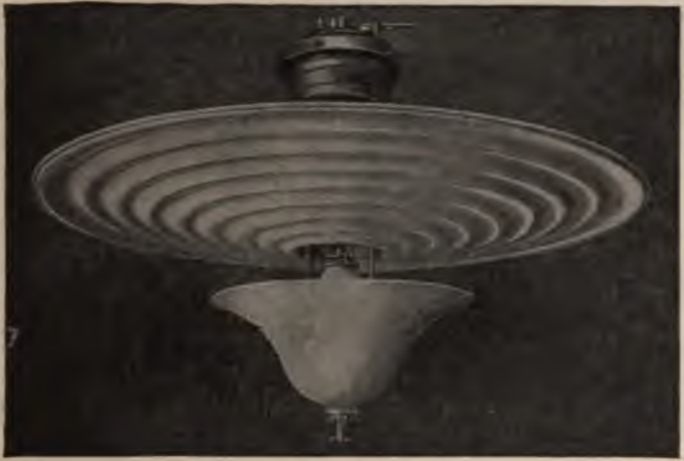


Fig. 48.

Holophane globes are made for both reflecting and diffusing the light, and they can be made to bring about almost any desired distribution with but a small amount of absorption of light. These consist of shades of clear glass having horizontal grooves forming surfaces which change the direction of light by refraction or total reflection as is necessary. The diffusion of light is effected by means of deep, rounded, vertical grooves on the interior surface of the globe. While these globes are of clear glass and absorb an amount of light corresponding to clear glass, the light is so well diffused that the filament of the lamp cannot be seen, and the globe appears as if made of some semi-transparent material. The objections to globes of this type are their high cost and the difficulty in keeping them clean.

Fig. 48 shows an enclosed arc lamp fitted with a shade and a concentric "diffuser". This shade is applied to an inverted arc, which is a direct-current arc in which the lower carbon is made positive. The effect of this combination is best shown in Fig. 49. Fig. 50 shows the change in the illumination curve produced by such shading. Inverted arcs have a considerable application when the light may be readily reflected and diffused as in lighting large rooms with light finish.

Fig. 51 shows another form of adjustable diffuser which finds application when a soft light is required for a definite direction. This shade is very readily adapted to shop lighting.

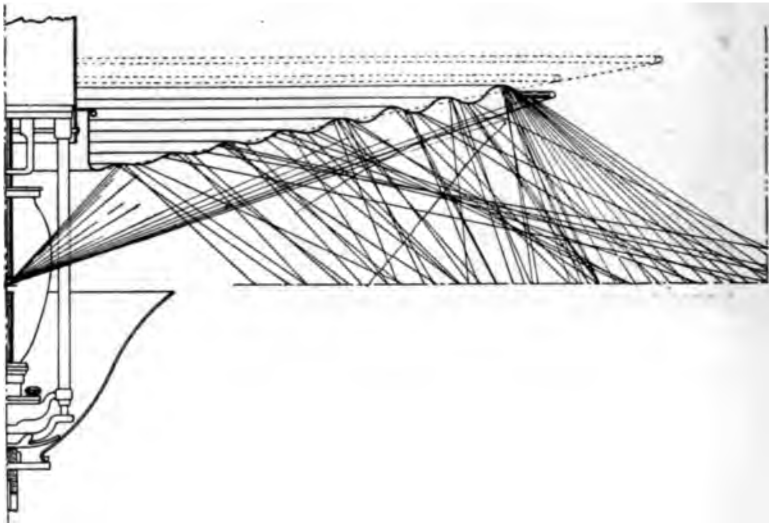


Fig. 49.

The use of opal enclosing globes is recommended for arc lamps used for street lighting for the reason that they change the distribution of the light so that it covers a greater area, and the light is so diffused as to obliterate shadows in the vicinity of the lamp. Table 11 gives the efficiency of different globe combinations for street lighting assuming the opal inner and the clear outer globes as 100%.

TABLE 11.

Opal enclosing and clear outer	100 per cent.
Clear " " clear "	91.2 "
" " " opal "	85.1 "
Opal " " opal "	82.7 "

PHOTOMETRY.

Photometry is the art of comparing the illuminating properties of light sources, and forms one branch of scientific measurement. Its use in electric illumination is to determine the relative values of different types of lamps as sources of illumination, together with their efficiency; also by means of the principles of photometry, we are able to study the distribution of illumination for any given arrangement of light sources.

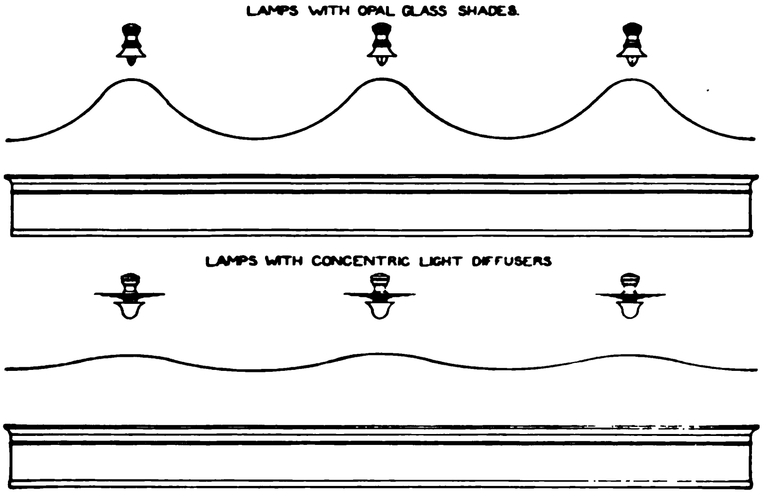

LAMPS WITH OPAL GLASS SHADES.
LAMPS WITH CONCENTRIC LIGHT DIFFUSERS

Fig. 50.

Light Standards. Inasmuch as sources of light are compared with one another in photometry, we must have some standard, or unit, to which all light sources are reduced. This unit is usually the candle-power and the rating of most lamps is given in candle-power.

While the candle-power remains the unit and is based on the standard English candle, other light standards have been introduced and are much more desirable.

The English Candle. The English candle is made of spermaceti extracted from crude sperm oil, with the addition of a small quantity of beeswax to reduce the brittleness. Its length is ten inches, and its diameter .9 inch at the bottom and .8 inch at the top, and its weight is one-sixth of a pound. Great care is t in the preparation of the wick and spermaceti. This candle burns with a normal height of flame of 45 millimeters and consumes 120 grains per hour when burning in dry air at normal atmospheric pressure. Under these conditions, the light given by a single candle is one candle-power.

When used for measurements, the candle should be allowed to burn at least fifteen minutes before taking any readings. At the end of this period the wick should be trimmed, if necessary, and when the flame height reaches 45 millimeters, readings can be taken. The candle should not require trimming when the proper height of flame has been reached. It is best to weigh the amount of material consumed by balancing the candle on a properly arranged balance when the first reading is taken, and again balancing at the end of a suitable period—ten to fifteen minutes. The candle-power of the unit is then, practically, directly proportional to the amount of the material consumed.

Fig. 51.

The objections to the candle as a unit are that it burns with an open flame which is subject to variation in height and to the effect of air currents. The color of the light is not satisfactory, being too rich in the red rays and the composition of the spermaceti is more or less uncertain.

The German Candle is made of paraffine, very pure, and burns with a normal flame height of 50 millimeters and is subject to the same disadvantages as the English candle. It may be necessary to trim the wick to keep the flame height at 50 millimeters. The light given is a trifle greater than for the spermaceti candle.

The Carcel Lamp is built according to very careful specifications and burns colza (rape seed) oil. It has been used to a large extent in France, but its present application is limited.

The Pentane Lamp is a specially constructed lamp burning pentane, prepared by the distillation of gasoline between narrow limits of temperature. This standard is not extensively used.

The Amyl Acetate Lamp. This lamp, known also as the Hefner lamp, is at present the most desirable standard. It is a lamp built to very careful specifications, especially with regard to the dimension of the wick tube. It burns pure amyl acetate and the flame height should be 40 millimeters. This flame height must be very carefully adjusted by means of gauges furnished with the lamp. Amyl acetate is a colorless hydrocarbon prepared from the distillation of amyl alcohol obtained from fusil oil, with a mixture of acetic and sulphuric acids, or by distillation of a mixture of amyl acetate, sulphuric acid, and potassium acetate. It has a definite composition, and must be pure for this use.

The most serious disadvantage of this standard is the color of the light, inasmuch as it has a decidedly red tinge and is not readily compared with whiter lights. Its value is affected somewhat by the moisture in the air and the atmospheric pressure, but it excels all other standards in that it is quite readily reproduced.

Below is given the accepted value of the English and German candle in terms of the Hefner unit.

The Paraffine Candle (Vereinskerze) at a flame height of 50 millimeters. } = 1.2 Hefner Units.

The English candle at a flame height of 45 millimeters.... } = 1.14 Hefner Units.

Working Standards. The units just described, together with some others, form reference standards, but an incandescent lamp is generally used as the working standard in all photometers. An incandescent lamp, when used for this work, should be burned for about two hundred hours, or until it has reached the point in the life curve where its value is constant, and it should then be checked by means of some standard when in a given position and at a fixed voltage. It then serves as an admirable working standard if the applied voltage is carefully regulated. Two such lamps should always be used—the one to serve as a check on the other; the checking lamp to be used for very short intervals only.

Photometers. Two light sources are compared by means of a photometer which, in one of its simplest forms, consists of what is known as a Bunsen screen mounted on a carriage between the two lights being compared, with its plane at right angles to a line passing through the light sources, and arranged with mirrors or prisms so that both sides of the screen may be observed at once. The Bunsen screen consists of a disc of paper with a portion of either the center, or a section around the center, treated with paraffine so as to render it translucent. If the light falling on one side of this screen is in excess, the translucent spot will appear dark on that side of the screen and light on the opposite side. Care must be taken to see that the two sides of the screen are exactly alike, otherwise there will be an error introduced in using the screens. It is well to reverse the screen and check readings whenever a new lot of lamps are to be tested. When the light falling on the two sides of the screen is the same, the transparent spot disappears. The values of the two light sources are then inversely proportional to the square of their distances from the screen. As an example, consider a 16 candle-power lamp being compared with a standard candle. Say the translucent spot disappears when the screen is distant 60 centimeters from the standard candle, we then have the proportion,

$$x : 1 = (240)^2 : (60)^2 = 16 : 1,$$

showing that the lamp gives 16 candle-power.

The above law is known as the law of inverse squares, and holds true only when the dimensions of the light sources are small compared with the distance between them, and when there are no reflecting surfaces present as when the readings are taken in a dark room.

The proof that the light varies inversely with the square of distance from the source is as follows:

Consider two spherical surfaces, Fig. 52, illuminated by a source of light at the center. The same quantity of light falls on both surfaces.

$$\text{Area of } S = 4\pi R^2 \text{ sq. ft. (R is in feet.)}$$

$$\text{Area of } S_1 = 4\pi R^2_1 \text{ sq. ft.}$$

Let Q = total quantity of light and q = light falling on unit surface. Then,

$$q = \frac{Q}{4\pi R^2}$$

$$q_1 = \frac{Q}{4\pi R^2_1}$$

$$q : q_1 = \frac{Q}{4\pi R^2} : \frac{Q}{4\pi R^2_1}$$

$$= 4\pi R^2_1 : 4\pi R^2$$

$$\frac{q}{q_1} = \frac{R^2_1}{R^2}$$

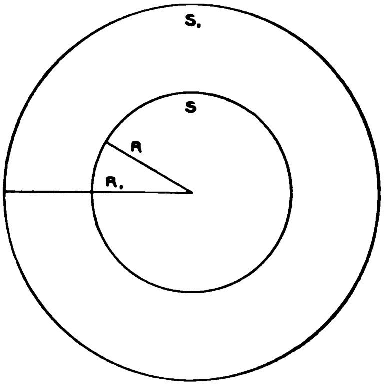


Fig. 52.

Fig. 53 shows the relation in another way. The area of C, distant two units from the source of light A, is four times that of B which is distant one unit.

The Lummer-Brodhun Photometer. In addition to the Bunsen Screen described, there are several other forms of photometers, the most important of which is the Lummer-Brodhun. The essential feature of this instrument is the optical train which serves to bring into contrast the portions of the screen illuminated by the t

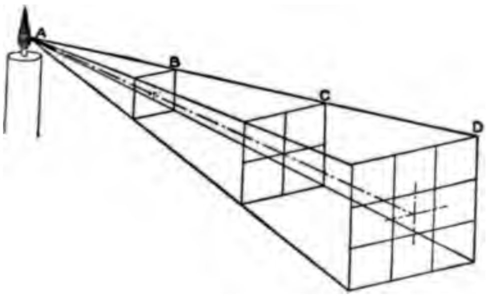


Fig. 53.

sources of light. Referring to Fig. 54, the screen S is an on screen which reflects the light falling upon it from L, to the mirror M, when it is again reflected to the pair of glass prisms A, B. The surfaces *sr* are ground to fit perfectly and any light falling on this surface will pass through the prisms. Light falling on the surface *ar* or *bs* will be reflected as shown by the arrows. We see then that the light from L, which falls on *ar* and *bs*, is reflected to the eye piece or telescope T, while that falling on *sr* is transmitted to and absorbed by the black interior of the containing box. Likewise, the light from the screen L_1 is reflected by the screen M_1 to the pair of prisms A, B. The rays falling on the surface *sr* pass through to the telescope T, while the rays falling on *ar* and *bs* are reflected and absorbed by the black lining of the case. The field of light, as then viewed through the telescope, appears as a disc of light produced by the screen L_1, surrounded by an annular ring of light produced by L. When the illumination on the two sides of the screen is the same, the disc and ring appear alike and the dividing circle disappears.

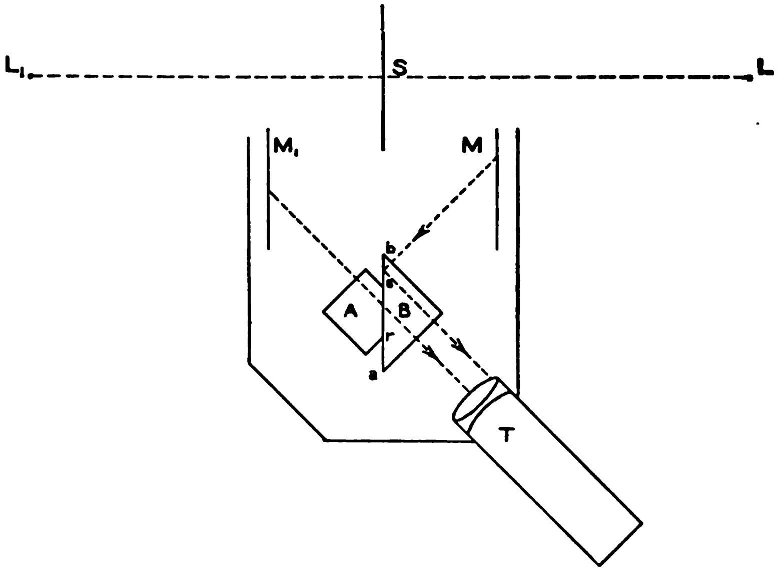


Fig. 54.

In using this screen, it is mounted the same as the Bunsen screen and readings are taken in the same manner. The screen and prisms are arranged so that they can be reversed readily and two readings should always be taken to compensate for any inequalities in the sides of the screen and the reflecting surfaces, a mean of the two readings serving as the true reading. This form of screen is used when especially accurate comparisons are required.

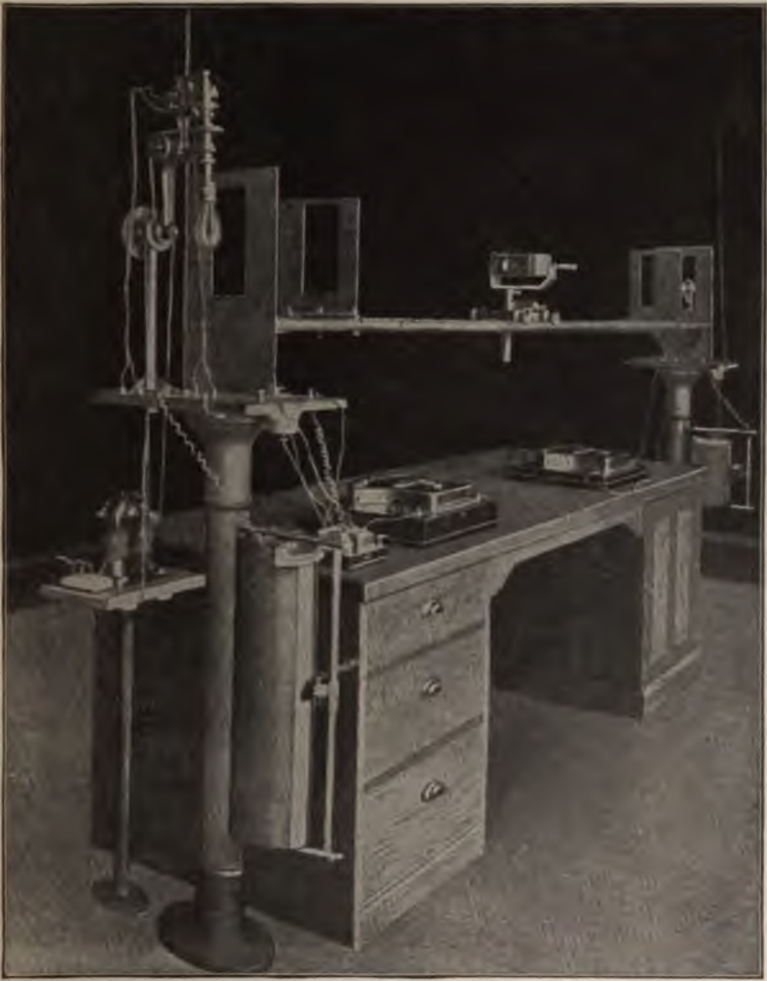


Fig. 55.

Fig. 55 shows a complete photometer with a Lummer-Brodhun screen, while Fig. 56 shows a Bunsen Screen and sight box.

In Fig. 55, the lamps are shaded by means of curtains so as to leave only a small opening toward the screen.

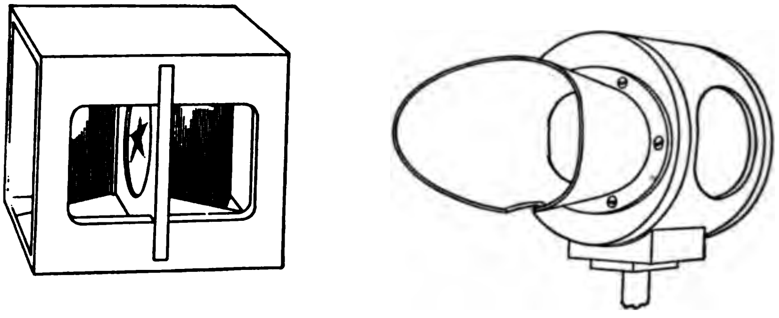


Fig. 56.

The Weber Photometer. As an example of a portable type of photometer, we have the Weber. This photometer, shown in Fig. 57, is very compact and is especially adapted to measuring intensity of illumination as well as the value of light sources; it may be used for exploring the illumination of rooms or the lighting of streets.

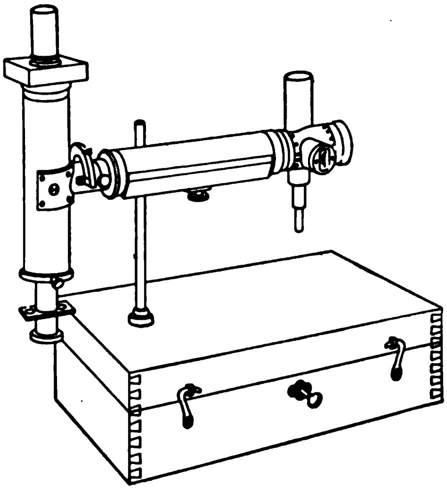


Fig. 57.

This apparatus consists of a tube A, Fig. 58, which is mounted horizontally and contains a circular, opal glass plate *f*, which is movable by means of a rack and pinion. To this screen is attached an index finger which moves over a scale attached to the outside of the tube. A lamp L, burning benzine, is mounted at the end of this tube. The benzine used should be as pure as possible, and the flame height should be carefully adjusted to 20 mm. when taking readings. At right angles to the tube A is mounted the tube B which contains an eye piece at O, a Lum-

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mer-Brodhun contrast prism at *p* and a support for opal or colored glass plates at *g*.

Operation. The tube B is turned toward the source of light to be measured, the distance from the light to the screen at *g* being noted. The light from this source is diffused by the screen at *g*, while that from the standard is diffused by the screen *f*. By moving the screen *f*, the light falling on either side of the prism *p* can be equalized. The value of the unknown source can be determined from the reading of the screen *f*, the photometer having previously been calibrated by means of a standard lamp in place of the one to be measured. The calibration may be plotted in the form of a curve or it may be denoted by a constant, C, when we have the formula,

$$I' = C \frac{L^2}{l^2}$$

C corresponds to a particular plate at *g*.

l = distance of screen *f* from the benzine lamp, and L = distance from the screen *g* to the light source being measured. Screens of different densities may be used at *g*, depending on the strength of the light source.

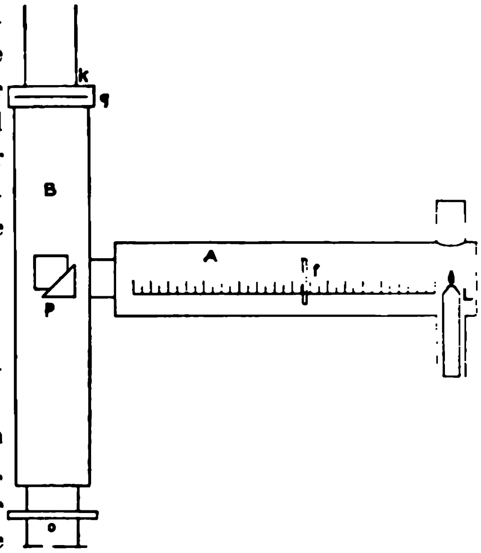


Fig. 58.

When used for measuring illumination, a white screen is used in connection with this photometer. The screen is mounted in front of the opening at *g*, and turned so that it is illuminated by the source being considered. Readings of the screen *f* are taken as before. A calibration curve is plotted for the instrument, using a known light source at known distance from the white screen when the instrument is mounted in a dark room.

A photometer, known as the **Matthews' Integrating Photometer**, has recently been placed on the market, and a very good idea

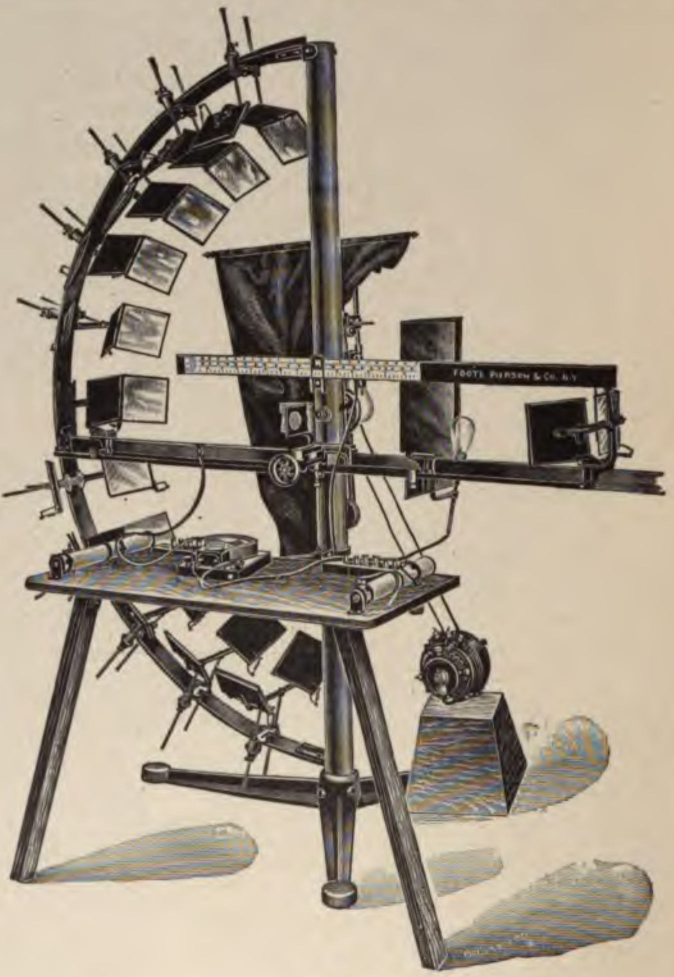

FOOTE PIERSON & CO. N.Y.

Fig. 59.

of its construction can be obtained from Fig. 59. By means of a system of mirrors, the light given by the lamp in several directions may be integrated and thrown on the photometer screen for comparison with the standard, the result giving the mean spherical candle-power from one reading. By covering all but one pair of screens, the light given in any one direction is easily determined.

Incandescent Lamp Photometry. *Apparatus.* Some sort of screen, either the Bunsen type or the Lummer-Brodhun screen preferred, should be mounted on a carriage moving on a suitable scale, and the lamp holders, one for the standard, the other for the lamp to be tested, are mounted at the ends of this scale. There are several types of so-called station photometers arranged so as to be very convenient for testing incandescent lamps. Fig. 60 shows one form of station photometer manufactured by Queen & Co. The controlling rheostats and shielding curtains are not shown here. Fig. 61 shows a form of portable photometer for incandescent lamps. The length of scale should not be less than 100 centimeters, and 150 to 200 centimeters is preferred. This scale may be divided into centimeters or, for the purpose of doing away with much of the calculation, the scale may be a *proportional scale.* This scale is based on the law of inverse squares and reads the ratio of the squares of the distances from the two lights being compared. If the standard used always has the same value, the scale may be made to read in candle-powers

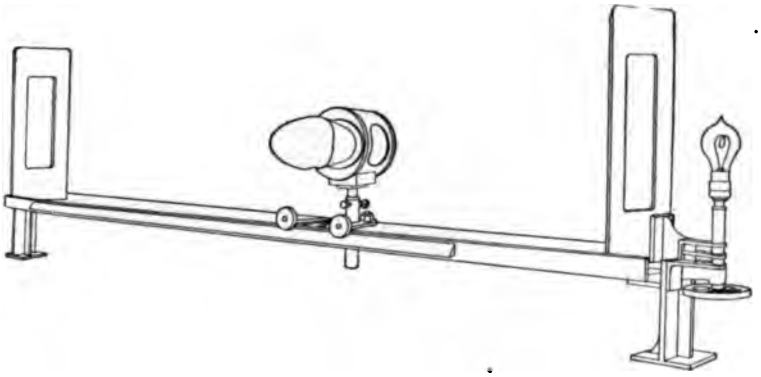


Fig. 60.

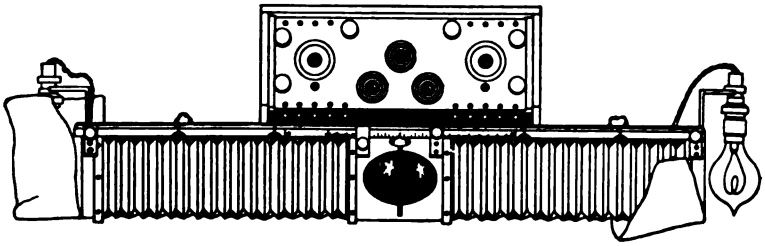


Fig. 61.

For mean horizontal candle-power measurements, the lamp should be rotated at 180 revolutions per minute, when mounted in a vertical position.

For distribution curves a universal lamp holder which will allow the lamp to be placed in any position, and which indicates this position, is used.

For mean spherical candle-power, the following method is used when the Matthews photometer is not available:

The lamp is placed in an adjustable holder and readings taken with the lamp in thirty-eight positions, as follows:

The measurement of the spherical intensity. For convenience the tip of the lamp and its base may be termed the north and south poles respectively.

"The mean of 13 readings taken at intervals of 30°, is taken to give the mean horizontal candle-power.

Beginning again at 0° azimuth, thirteen readings are made in the prime meridian or vertical circle, the interval again being 30°, and the last reading checking the first.

It will be noticed that four readings, two being check readings, have been made at 0° azimuth in each case. The mean of the four is taken as the *standard reading*, it being the value of the intensity, in this position, should the lamp be used as a standard.

Additional sets of thirteen readings each—the last reading checking the first one—are similarly made on each of the vertical circles through 45°, 90°, and 135° azimuth.

In combining the readings for the mean spherical intensity, a note is taken of the repetitions.

Neglecting the repetitions, which may also be omitted in part, in the practice of the method, there remain thirty-eight points, as follows:

	Distributed Values.
The mean of four measurements at the north pole of the lamp......	1
Four measurements on each of the vertical circles through 0° and 90° azimuth at vertical circle readings of 60°, 120°, 240°, and 300°.	8
Four measurements on each of the vertical circles through 0°, 45°, 90°, and 135° azimuth at vertical circle readings of 30°, 150°, 210°, and 330°..	16
Twelve measurements 30° apart at the equator....................	12
Four null values at the south pole of lamp.........................	1
Total number of effective measurements.........................	**38**

The points thus laid off on the reference sphere are approximately equidistant, being somewhat closer together at the equator than at the poles."

When the lamp is rotated, readings are taken for each 15° or 30° in inclination, from 0° to 90°, and from 0° to 270°. These are integrated values for their corresponding parallels of latitude on the unit sphere.

The mean spherical candle-power from these readings may best be obtained by plotting a distribution curve from the readings, determining the area of this closed curve by means of a planimeter and taking the radius of an equivalent circle as the value for the mean spherical candle-power.

In all tests the voltage of the lamp must be very closely regulated. A storage battery forms the ideal source of current for such purposes. In testing incandescent lamps a standard similar to the lamp being tested is desirable and it should, preferably, be connected to the same leads. Any variation in the voltage of the mains then affects both lamps and the error introduced is slight.

Arc Light Photometry. Owing to the variation of the amount of light given out by an arc lamp in one direction at any time, due to variation of the qualities of the carbons, position of the arc, and also on account of the color of the light, etc., the photometry of arc lamps is much more difficult than that of incandescent lamps. The curves shown in Figs. 10 and 11 are average distribution curves taken from several lamps and will vary considerably for any one lamp. If the arc is enclosed, this variation is not so great.

The working standard should be an incandescent lamp run at a voltage above the normal so that the quality of the light will compare favorably with that of the arc. Since an incandescent lamp deteriorates rapidly when run at over voltage, the standard can be used only for short intervals and must be frequently checked.

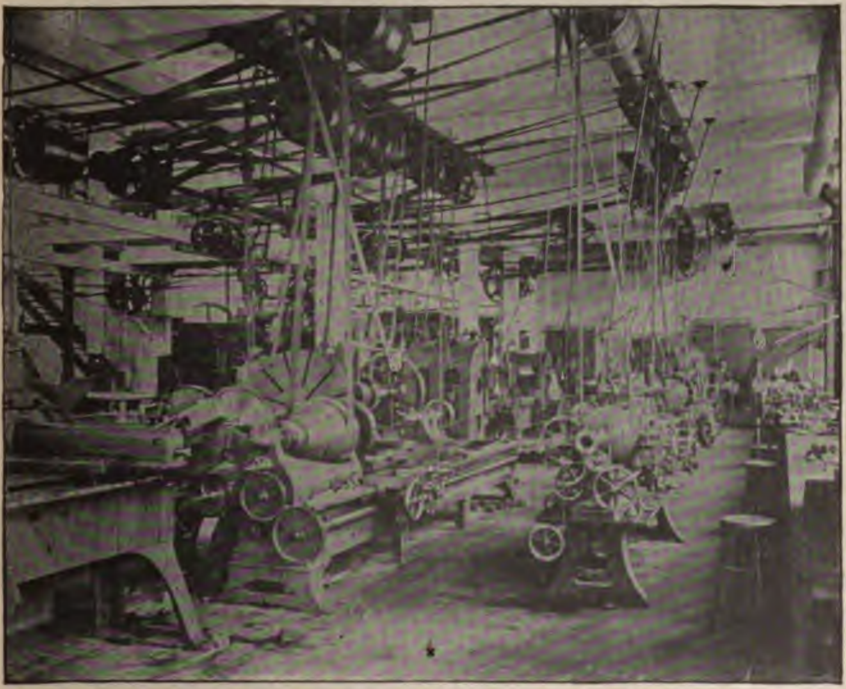
Since an arc lamp can be mounted in one position only, mirrors must be used to obtain distribution curves. A mirror is used mounted at 45° with the axis of the photometer, and arranged so as to reflect the arc when in different positions. A mirror absorbs a certain per cent of the light falling upon it and this per-must be determined by using lamps previously standardized. The length of the photometer bar must include the distance from the mirror to the arc.

The Weber photometer is well adapted to arc-light measurements inasmuch as appropriate screens may be used to cut down the intensity of the light.

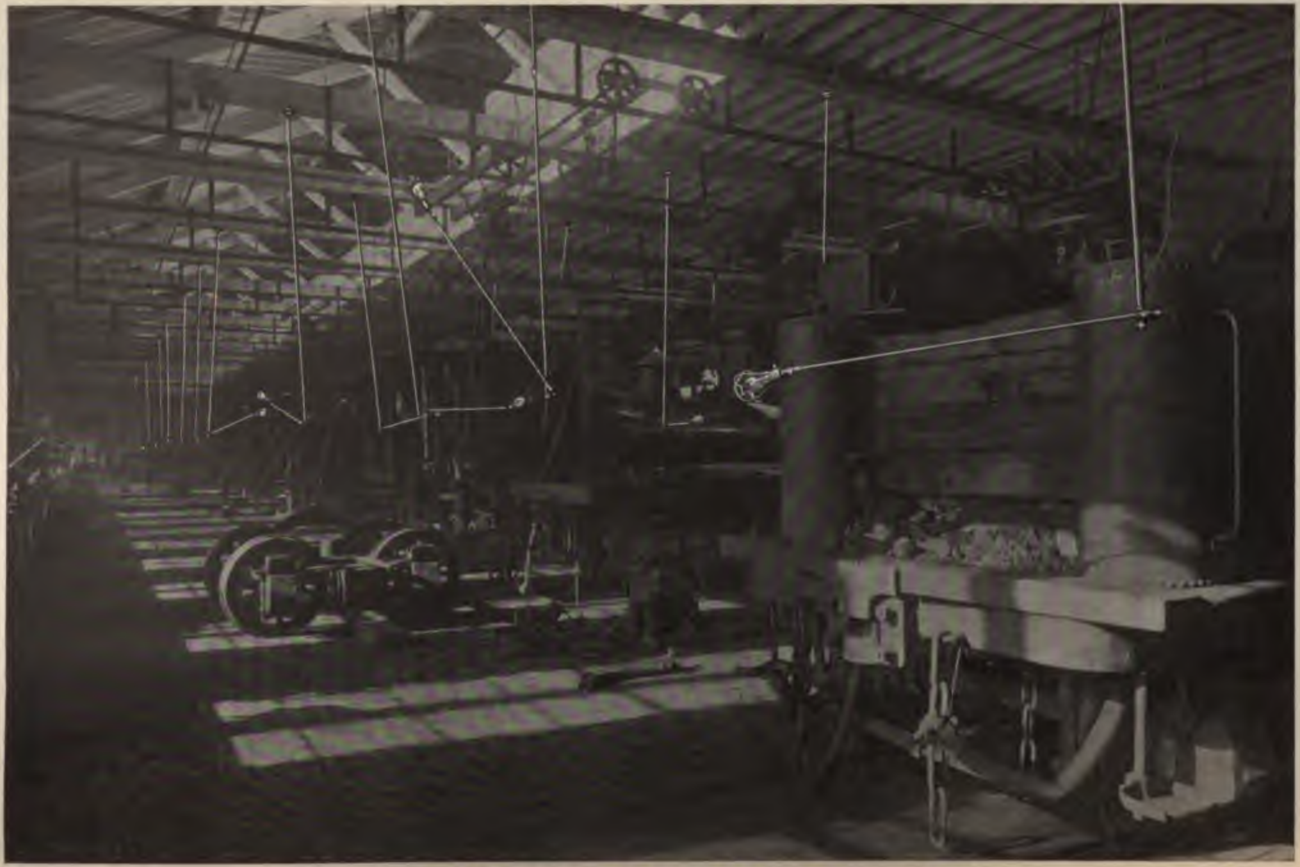
A special form of the Matthews' photometer is also used for testing arc lamps.

SHOP LIGHTING.

It is only within a few years that what is now regarded as proper attention to lighting has been considered in the design and construction of factory buildings. Formerly, a shop seemed to be designed more to protect the tools and materials from the weather, than to afford any degree of convenience or comfort for the workmen. It is now regarded as good business policy (in other words, it pays) to provide buildings which are properly heated, lighted, and ventilated. In such buildings, it has been found that workmen are more content, do better work, and produce more. From the old-fashioned blacksmith shop, in which each smith was supposed to work by the light of his own fire, it is a far cry to shops such as those of the National Cash Register Company at Dayton,



BOSTON & ALBANY RAILROAD MACHINE SHOP, WEST SPRINGFIELD, MASS.
Equipped with White Adjustable Fixtures.



INTERIOR OF REPAIR SHOP, BOSTON AND ALBANY R.R., ALLSTON, MASS.

Incandescent Lights with White Adjustable Fixtures.

Ohio, in which the comfort and convenience of the employees has been given a degree of attention that seems to the old shop managers to partake of the nature of coddling.

DISTRIBUTION OF SUNLIGHT.

In considering this question of lighting, it is well understood that daylight is the best light, especially when it is not accompanied by the direct rays of the sun. To properly distribute daylight—which is, of course, the cheapest light—over large areas, is the first problem to be considered in the design of new shop buildings. This may be accomplished in a number of ways. Where buildings are several stories in height, and where light, except in the upper story, must be admitted from side windows, those windows should reach from the top of the bench to the ceiling. A given amount of glass arranged in this manner gives a much better general distribution of light than the same amount of glass put into the ordinary form of short windows. The amount of light in the center of the room depends very largely upon the height of the windows at the side. All modern factory buildings

WHITE ADJUSTABLE FIXTURES IN WORCESTER SAFE DEPOSIT & TRUST COMPANY. WORCESTER, MASS.

are now lighted by long, narrow windows. The common type of shop, consisting of an open floor with a gallery on both sides, is usually lighted, in addition to the tall side windows, by glass in the sides of the monitor roof. If these monitor windows are kept clean, they add greatly to the light of the main floor.

The best system of roof lighting is by means of what is termed a "saw-tooth" roof, the short and comparatively steep side of the tooth being composed wholly of glass. This glass should face as nearly north as possible, in order to avoid the direct sunlight. In this connection, it will be remembered how the workmen of the old school, especially if employed on work requiring close application, always selected a north window, even if the view therefrom was not so pleasing as that from some other point of the compass. This saw-tooth roof may be used on the top of a monitor in place of side windows, and it results in a much better lighted floor.

WELSBACH BURNER,
With silvered glass reflector.

Old shops, in which a change in amount or location of glass area is impossible, can have their light increased in amount and better distributed by a judicious arrangement of machines, and, particularly, by keeping the walls and ceilings as nearly pure white as possible. Whitewash is so cheap and so easily applied by modern pneumatic methods, that there is little or no excuse for neglect in this particular. Whitewash can easily be made so that it will not readily rub off, in fact, so that it can be washed; but in most cases a fresh application is preferable to cleaning The removal of all possible belting (which can be accomplished by electric driving, either individually or by the group system) adds largely to the lighting effect, and also, by the suppression of dust and flying oil, keeps the walls and ceilings in much better condition. Some factories carry this whitening effect to the point of having the machine tools painted white and varnished. This not only avoids dark spots in the room, but shows plainly any neglect of machinery. In a shop equipped in this manner, the dirty and slothful workman is entirely out of place, and he usually changes his habits or seeks some other shop where his natural conditions prevail.

ARTIFICIAL LIGHTING.

Artificial lighting, which is usually required in northern latitudes, may be divided into three classes: General lighting, individual lights, and portable lights.

Lighting by candles, except in some cases of portable lights, has entirely disappeared; but many country shops still have to depend upon oil as an illuminant. In such cases, large lamps of the Argand type are suspended from the ceiling for general illumination, and small flat-wick lamps, preferably on swinging wall brackets, are used for the individual. The quality of this illumination depends, first, upon the care of the lamps, and, second, upon the quality of the oil. Oil lights at best are dirty and entail a large amount of labor. They are objectionable in that they must be kept from draughts of air, which smoke the chimneys, and thus the shop is often deprived of proper ventilation.

Gas is more frequently used for shop lighting than any other artificial illuminant. It may be classed under the heads of oil gas, coal gas, natural gas, and acetylene. For the isolated shop, oil gas and acetylene are particularly adapted, as such gas plants are easily installed and require but little attention. In every case, the gas plant should be entirely separate from the factory building, and preferably under ground. While acetylene furnishes a light almost ideal in character, it is particularly poisonous, although leakage is readily detected by its odor. A more serious drawback is that this gas forms violently explosive compounds when mixed with air in comparatively small proportions. Many serious and some fatal accidents have occurred by failure to realize the importance of this fact. These installations should be made only by those thoroughly familiar with the subject, and their use must be carefully guarded.

Coal gas is very largely used for shop lighting, on account of its comparative cheapness and the fact that, even in small cities, it can be readily obtained. As it is also used in many shops for heating, in connection with the Bunsen burner and blowpipe, it serves a double function which renders it peculiarly adapted for factory purposes. The ordinary open fish-tail burner, consuming about six cubic feet per hour, is the type of burner generally used. This light is objectionable on account of the fact that it vitiates the air; this, in the winter months when the windows are closed, becomes a serious matter, and calls for largely increased ventilation. The light flickers, even in still air, which makes it very trying to one's eyes when engaged on fine work, and this difficulty is further increased by currents of air caused by open windows or moving belts.

ORDINARY WELSBACH BURNER.

THE WELSBACH BURNER.

Ordinary illuminating gas used in connection with a Welsbach burner, furnishes a very steady light with about one-half the gas consumption necessary for the open light. The Welsbach light is best suited for general lighting, where two or more burners are contained in the same globe and suspended from the ceiling. As an individual light, the Welsbach is not in great favor, on account of its ghastly color combined with a faint tinge of green, which renders it objectionable to many workmen. The mantle used in the Welsbach light is extremely fragile, and it is quickly put out of commission by shocks, vibration, and air currents. For these reasons it is not so well suited for use in the shop as it is for domestic purposes. The Welsbach light, however, is not dependent upon the illuminating quality of the gas, but upon the incandescence of the mantle, which may be produced by any form of fuel gas without the enriching necessary to make it suitable for use in an open burner. Natural gas, therefore, which is used for heating in many sections of the country, can also be used for lighting if employed in the Welsbach burner. As this gas is very cheap, it often pays to use it in this manner.

Open—Arc Lamp, Double.
Old Style.

Open—Arc Lamp, Single.
Old Style.

White Adjustable Ceiling Fixture for Incandescent Light. Style A.

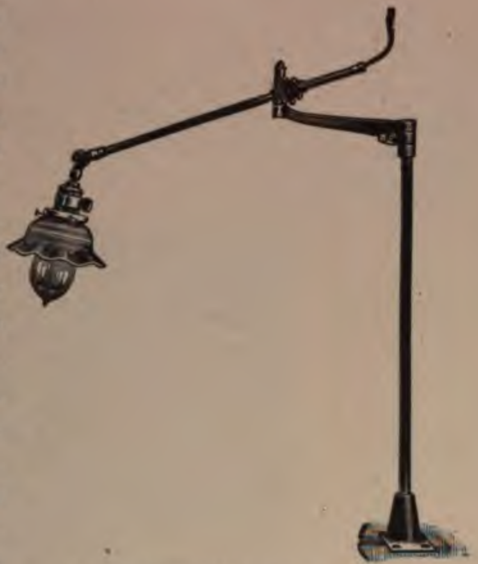
ELECTRIC LIGHTING.

Electric lighting is rapidly being introduced for shop purposes, especially when the current is generated in the factory. The arc light is commonly used for general illumination, and the incandescent light for the individual. The open arc light is being supplanted by the enclosed arc, with a distinct gain in economy and safety. The open arc, even with the best quality of carbon, is somewhat noisy, and is subject to disagreeable flickering, while the falling of pieces of incandescent carbon, is not only annoying, but dangerous. The enclosed arc light requires less frequent trimming, is more steady, and owing to the fact that it is enclosed, it absolutely prevents danger from falling particles of carbon. Arc lights for general illumination are usually in the vicinity of 1,200 candle-power.

ENCLOSED ARC LAMP.
GLOBE IN TRIMMING POSITION.

WESTINGHOUSE SERIES—ALTERNATING
ENCLOSED—ARC LAMP.

The 16-candle-power incandescent lamp is generally used for individual light; but the 8-candle-power lamp, with a suitable reflector, is less dazzling and furnishes all the light necessary. The system adopted in some drafting rooms, of using an inverted arc—that is, one with the crater in the lower carbon—combined with a reflector to throw the light directly to the ceiling, results in a uniformly diffused light. This avoids the sharp shadows cast by the direct light from the arc, and has much to recommend it as a shop light, especially if the ceilings and walls are kept white.


WHITE ADJUSTABLE BENCH FIXTURE INCANDESCENT LIGHT. Style D.

There are several styles of fixtures used in connection with the incandescent light to place the lamp in any desired position, as the ordinary drop light is very inconvenient in this particular. The White fixture, with its ball-and-socket joint, is one of the best.

In connection with the question of electric lighting, the necessity of maintaining a constant voltage is one that is not given the

COOPER HEWITT LAMP FOR GENERAL INTERIOR LIGHTING.
Type H 7, an improved form of Type V 5. Can be operated in horizontal, vertical or inclined position.

attention it deserves. It is almost impossible to secure satisfactory lighting from a generator driven by the main engine, and this is especially true if electric cranes are also operated from this generator. In the best practice it is considered necessary to have a separate engine and generator to be used solely for the lighting system. A generator driven by the main engine is found satisfactory for crane service.

COOPER HEWITT LAMP FOR INTERIOR LIGHTING WHERE MODERATELY STRONG ILLUMINATION IS DESIRED.

Designed for series installation—two in series on 100 to 120 volts direct current. Suspended at an angle of 20° from ceiling or fastened to wall. Type H 6.

The Cooper Hewitt Light. The Cooper Hewitt mercury vapor lamp is the cheapest form of electric lighting, and will undoubtedly be the commercial light for factory use, especially in shops doing a fine class of work. The color of this light, due to the total absence of red rays, is objectionable but not injurious; and further experiments will undoubtedly produce a light based on this principle which will meet many requirements.

For portable lighting, there is nothing at present superior to the incandescent lamp, for, by means of a long flexible cord, it can be taken to any position. The incandescent lamp, furnished with a magnetic base, can be attached to any iron or steel surface, where it will remain until the light is extinguished. For erection work, particularly, this type of lamp is peculiarly adapted.

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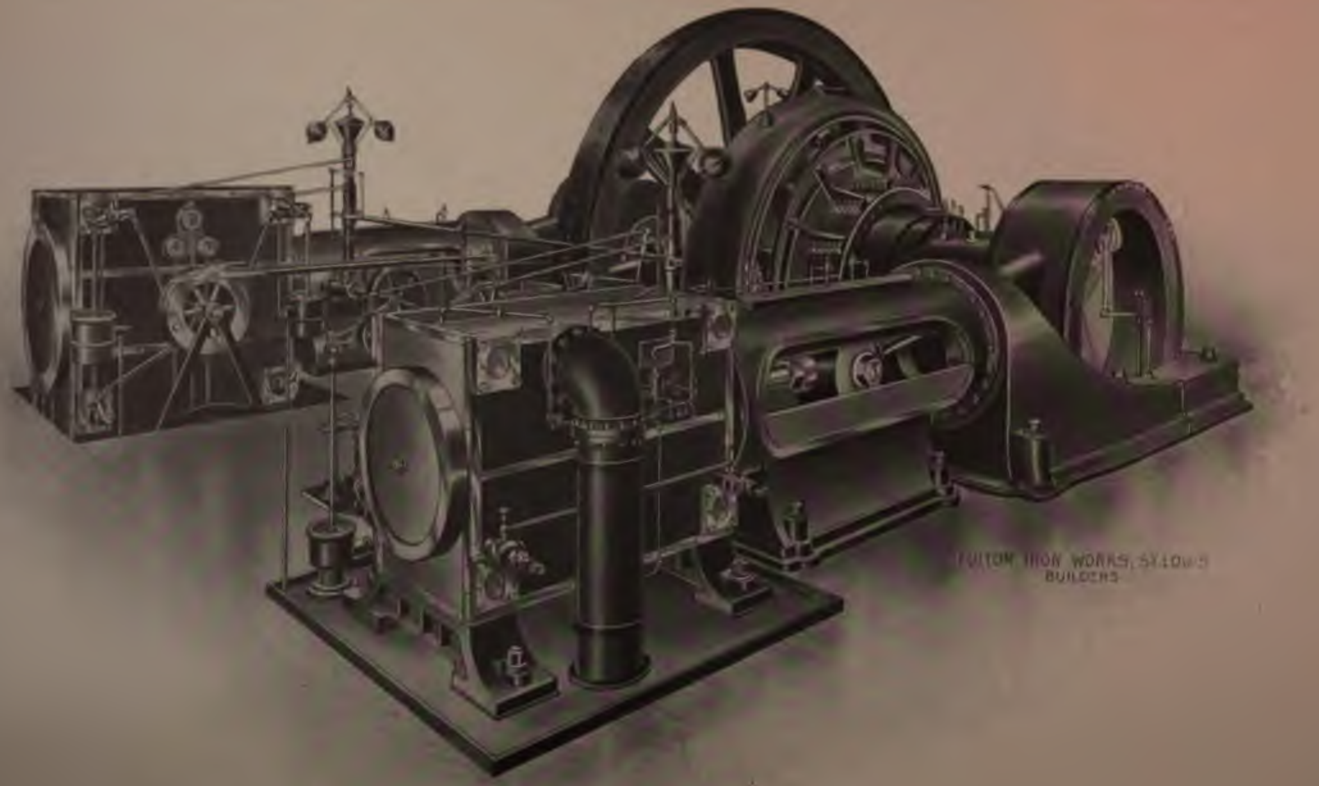
ASTOR, LENOX
TILDEN FOUNDATIONS


FULTON IRON WORKS, ST. LOUIS
BUILDERS

HEAVY-DUTY CROSS-COMPOUND CONDENSING ENGINE, DIRECT CONNECTED TO 1,500 K.W. RAILWAY GENERATOR.

St. Louis Transit Company's Power House.
Fulton Iron Works.

ELECTRIC RAILWAYS.

THE general name "electric railway" is applied to all railways employing *electric motors* to supply power for the propulsion of cars. On all electric railways in commercial use today, the electric motor is used to furnish power to the driving wheels of the car or locomotive, the electric motor being the most efficient known means of transforming electrical into mechanical energy.

Electric railways are usually classified according to the methods by which current is supplied to the moving car. Thus, where an overhead trolley wire is used, as on the great majority of electric railways, the term **trolley road** is applied. Where an insulated steel rail is laid alongside the track rail for supplying current, as on the "elevated" roads in America and on a few interurban roads, the term **third-rail road** is used. Where, as on the street railways of a few large cities, the conductors are placed in a conduit underneath the surface of the street, and current is taken by means of a plow or shoe running in the conduit, the name **electric-conduit railway** is most commonly applied. There are also a few systems using conductors buried beneath the pavement, and having contact buttons or sections of conductor rail on the street surface, which sections are supplied with current by automatic electro-magnetic switching apparatus as the car passes, but which are normally dead and harmless. The overhead trolley and the third-rail systems are by far the most common.

A further general classification of electric railways has recently been made because of the introduction of alternating-current railway motors. The great majority of electric railways employ direct-current motors. Where alternating-current motors are used, the road is spoken of as one using single-phase alternating-current motors or three-phase alternating-current motors, as the case may be.

All electric railway systems in commercial use are operated on an approximately constant potential or voltage, and the various electric motor cars operating on the system are connected across the lines in parallel. The most common practice is to utilize the rails and ground as one side of the circuit, and the overhead trolley wire or "third rail" as the other side, as in Fig. 1. The trolley wire or third rail is, of course, thoroughly insulated from the ground.

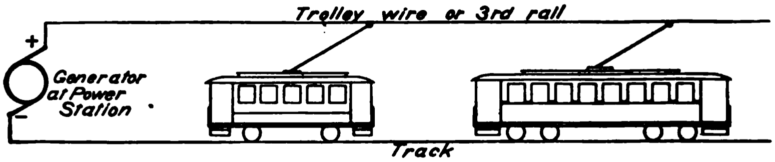


Fig. 1.

The positive poles of the generators at the power house are usually connected to the trolley wire, and the negative poles to the rails and ground. The various electric motor cars, being connected in parallel or multiple between the trolley wire and the ground, draw whatever current is necessary for their operation. Where the conduit system is used, both sides of the circuit are insulated from the ground, and the contact shoe or plow collects current from two

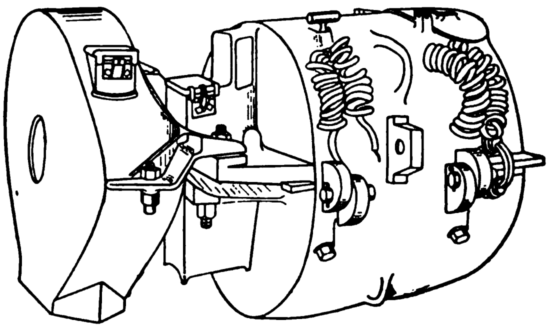


Fig. 2. Railway Motor.

conducting rails in the conduit, one of these conducting rails being positive and the other negative. A double-trolley system is also in use to a limited extent. In this system, both the positive and the negative sides of the circuit are insulated from the ground, one trolley wire being positive and the other negative.

Further discussion of the matters just outlined will be taken up in the succeeding pages.

CAR EQUIPMENT.

MOTORS.

The voltage most commonly employed by electric railways is 500 to 600; and the motors are 500-volt direct-current series-wound motors, designed especially for railway service. The electric railway motor must be dustproof and waterproof because of the position it occupies under the car. For this reason electric railway motors are made in the form of a steel case (Fig. 2), which entirely surrounds the field-magnet poles and takes the place of the yokes or frames that support the fields on stationary motors. Cast steel is the material now usually employed for railway motor cases and fields, on account of its mechanical strength and its high magnetic permeability. The four poles project inwardly from the case, as seen in the open motor case, Fig. 3, which is that of a Westinghouse No. 69 motor.

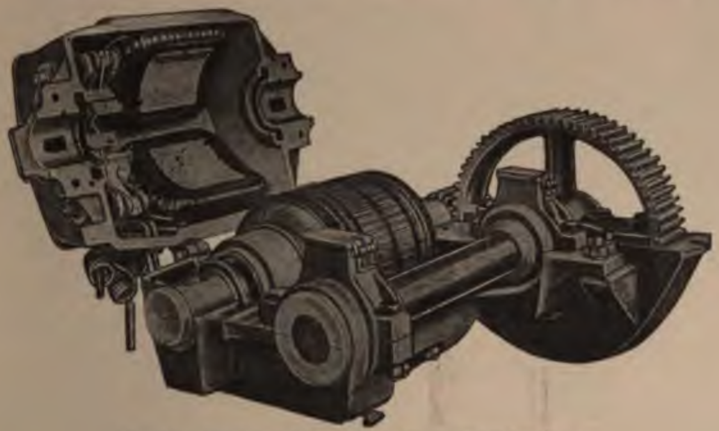


Fig. 3. Railway Motor. Upper Field Raised.

Railway motors have usually four poles because this permits of a symmetrical and economical arrangement of material around the armature, and hence permits the motor to be placed in the small space available on the car truck. Two-pole motors have been used in the past, but they are not as compact as the four-pole type.

Armature Winding. The armature winding is what is commonly known as the series or wave winding, shown developed in the paper on Direct-Current Dynamos. This winding is sh in Fig. 4, which is an end view of an armature and commuta In the figure, however, the armature is shown with a much sma number of slots than a railway armature should have in prac One reason for the employment of the wave or series winding railway motor armatures, is that with this winding no cross-c nections are necessary when only two brushes are used, and t two brushes may be placed 90° apart in a convenient and ac sible position. Another reason is that the current, in flow from one brush on the commutator to another, must always through the magnetic field of two poles; that is, it must alw pass through two sets of c This makes it impossible for unbalancing of the magnetic cuit to cause more current to through one portion of the ar ture than is flowing through other portion. In a railway m it has been found quite possibl have one pole or pair of poles erting a greater magnetic attrac on the armature than another p owing to differences in the i and differences in the clearance tween the armature and pole-pieces, which differences cause m magnetic lines of force to flow from some pole-pieces than fr others. With the lap-armature or the ring-armature winding, si the various portions of the armature under different poles are parallel with one another, any difference in the magnetic flux tween different poles will cause a different amount of curren flow in the various paths through the armature.

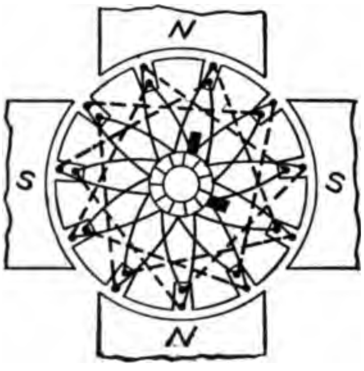


Fig. 4. Armature Winding.

Armature Coils. Railway motor armatures are today versally constructed with form-wound coils, which are wound a form of proper shape and carefully insulated before being pla in the armature.

Armature Leads and Brushes. In Fig. 3 is seen a c pleted armature in the motor casing of a Westinghouse No. motor. Since the motors are four-pole, the two sides of any coil occupy slots 90° apart in the armature coil, as indicated in Fig. 4. The ends of the coils are connected to commutator bars 180° apart. The relative position of the commutator connections of any armature coil can, of course, be varied so as to bring the brushes in the most convenient position in the motor casing. Brushes are always of carbon, and are placed where they can be easily reached from the opening in the motor casing over the commutator.

Opening Cases for Inspection. Accessibility for inspection and repairs is essential in all railway motors. A lid is always provided directly over the commutator to facilitate inspection of the commutator and brushes. To open up the motor casing for more extensive inspection or repairs, three general schemes are employed. One is to have the lower half of the casing swing downward on a hinge as in Fig. 5, which illustrates the Westinghouse No. 38B motor. The armature may be placed either in the lower half, as shown in Fig. 5, or in the upper half. When a motor of this type is to be opened the car is run over a pit, and the repair men work entirely from below.

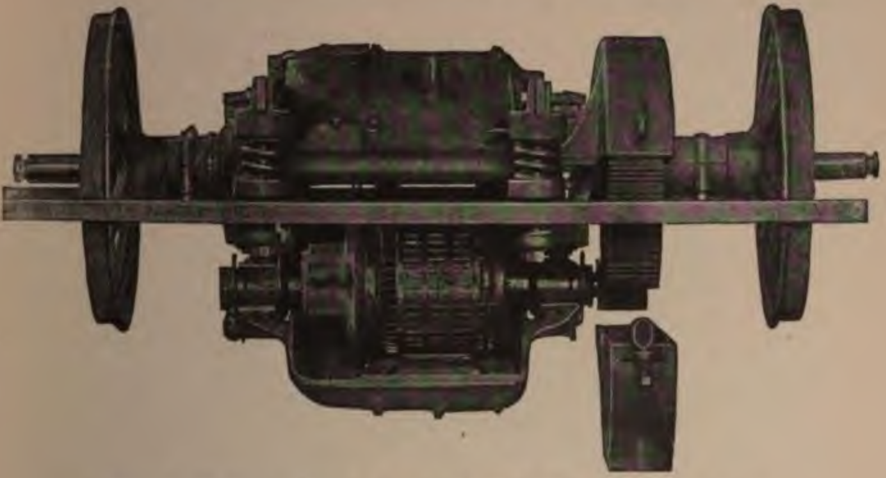


Fig. 5. Railway Motor. Lower Half of Casing Swung Down.

Another scheme is to have motors open from the top, either by hinging the upper part of the motor casing, as in Fig. 3, or by having the top part of the casing lift off. Where this form of motor is used, the car body is hoisted clear of the truck, and the trucks are run out from under the car body before work is done on the motors. In this case, all the work can be done from above without the use of pits.

A third design is the box-frame motor casing, from which the armature can be removed endwise only. Such an arrangement is shown in Fig. 6, which is a view of a No. 66 motor of the General Electric Company. In this motor a sufficiently large opening is provided in the ends of the motor casing to permit of the armature being removed endwise. A plate or head, which accurately fits into this opening, carries the armature bearing. In removing armatures from motors of this kind, the usual method is to take the motor out of the trucks and stand it on end with the pinion up. The bolts being removed from the end plate, the armature can then be hoisted out of the case by means of a special hook attached to the pinion. Another plan that has been used in removing armatures from such motors, is to place the motor in an apparatus where the armature shaft can be held between centers, as in a large lathe. The motor casing is then moved along in a direction parallel to the armature shaft, until the armature is exposed.

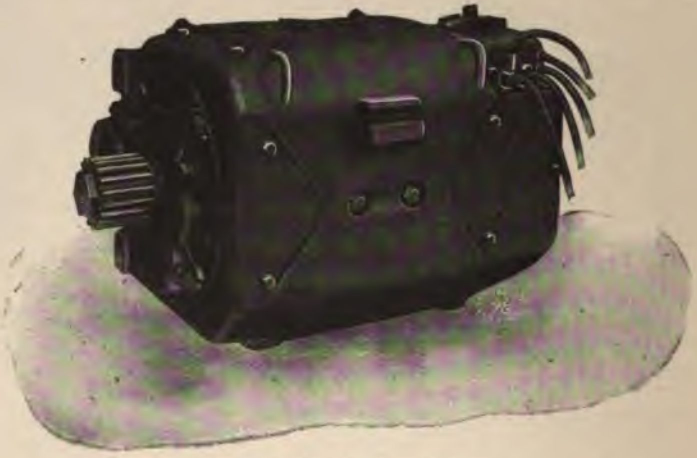


Fig. 6. Box-Frame Motor.

This latter box-frame type of motor is very compact; a stronger casing can be made for a given weight and space than if it were divided horizontally. Moreover, the magnetic circuit cannot be disturbed by imperfect contact between two parts of the casing. Where this type of motor is used, the bearings project inward under the commutator and armature, thus getting long bearings with a short motor, which is important where the room is limited, as, for example, in the case of a large motor mounted on a standard-gage truck.

Gearing. In most cases, spur gearing is used to transmit power from the armature shaft to the car axle, although a few motors with armatures mounted directly on the car axle are in use. Various gearings other than the simple spur gear have been tried, such as worm gears, chain and bevel gears. Practically all have been abandoned in favor of the single-reduction spur gearing, which is the most satisfactory from the standpoint of wear and efficiency. This gearing is shown in Figs. 3 and 5. The gearing is covered with a gear case (Fig. 5), which is usually of steel though gear cases of thin sheet metal and wood are sometimes used.

Lubrication. The lubrication of railway motors was for a number of years carried on almost exclusively with grease, which it was customary to place in the gear casing and in grease boxes over the armature and car-axle bearings. Grease becomes most efficient as a lubricant only when the bearing is heated sufficiently to make the grease run like oil. Oil is now being used to a considerable extent, especially for larger motors. It is fed to the bearings by various devices that allow a very slow feed, such as wicks and lubricators adjusted to pass a small amount of oil per hour.

Bearings. Railway motor bearings are usually of Babbitt metal, which metal is cast into a steel shell. This shell fits into receptacles in the motor casing, which can be seen in Figs. 3 and 5. A steel shell is used so that the worn-out bearings can be easily renewed and the shells taken to a Babbitt melting furnace to have new Babbitt poured into them.

Motor Suspension. Two methods of suspending motors flexibly on trucks are in common use. That end of the motor which has bearings on the car axle, cannot, of course, be flexibly suspended with regard to the axle; but the other end of the motor can be placed on springs, or rest on a bar supported on springs, as shown in Fig. 7 This suspension is commonly called **nose suspension.** Instead of having a special bar and special springs for the nose of the motor, the nose may rest upon some part of the truck that is carried upon springs. Thus, on the M. C. B. type of swivel truck, the nose usually rests on the truck bolster, and thus gets the benefit both of the bolster springs and of the equalizer springs of the truck. Another general plan of suspension is that known in one form as **cradle suspension,** and in another form as **side-bar suspension.** A side-bar suspension is shown in Fig. 8. Here a

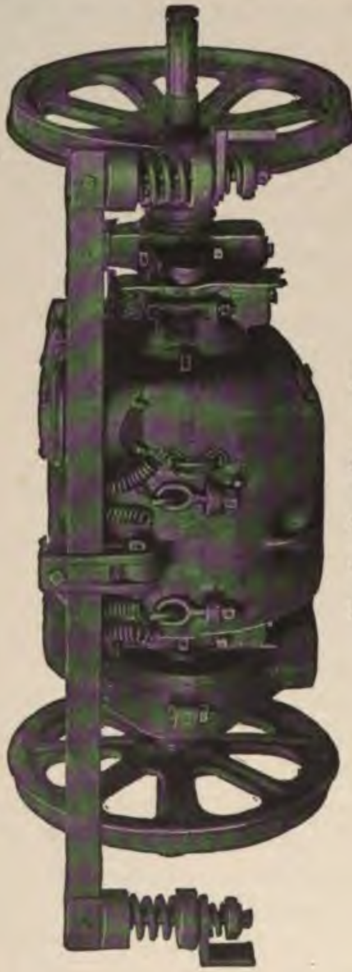


Fig. 7. Nose Suspension.

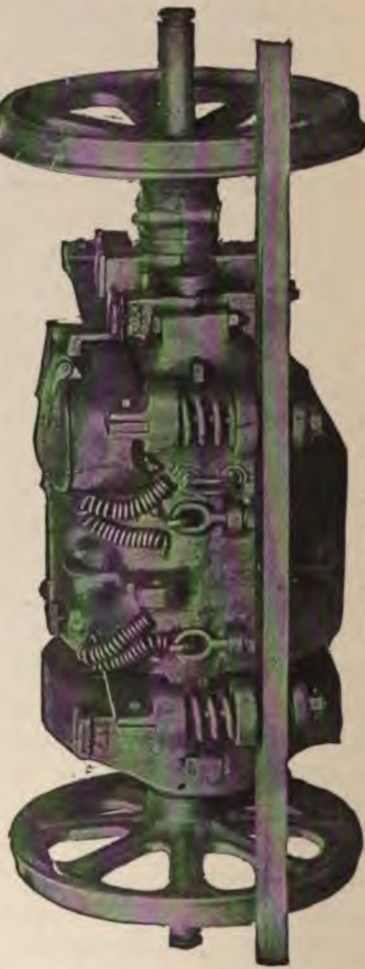


Fig. 8. Side-bar Suspension.

larger percentage of the weight of the motor, is evidently taken by the springs than in the case of nose suspension. It is desirable to relieve the car axle of as much dead weight as possible. By dead weight is meant weight resting upon it without the intervention of springs.

CONTROLLERS.

In an ordinary electric car, current is taken from the wire through the trolley wheel and pole, and is first led from the trolley base through overhead switches or a circuit-breaker, and then to the controller, from which it passes through the motors and thence through the motor frames, car truck, and wheels to the rails and ground. If the car is designed to be operated from either end, an overhead switch or circuit-breaker is placed over each platform of the car so that current can instantly be cut off entirely from the controllers by throwing the switch or circuit-breaker at either end of the car.

The lighting circuit is run from the trolley base independently of the motor circuit, and has its own switch and fuse-box. Current for the lights is taken from the trolley circuit before it reaches the main switches or circuit-breakers. Current for electric heaters, if such are used, is likewise taken from a separate circuit. On a 500-volt system five 100-volt lamps are usually connected in series for car lighting. As many multiples of five can be employed as are necessary to light the car.

Rheostat Control. The simplest form of controller is that employed where only one motor is used on a car. A rheostat is placed in series with the motor when started, just as on a stationary motor; and the function of the controller is to short-circuit this resistance gradually until it is entirely cut out and the motor operates with the full voltage. The controller also has a reversing switch by means of which the relative connections of the armature and fields are reversed, which, of course, changes the direction of rotation of the motor armature. Such a simple equipment as this, however, is rarely to be found in practice.

Series-Parallel Control. Single-truck cars usually have two motors, one on each axle; and on such cars a series-parallel controller is the kind usually employed. Diagrams of connctions on the various points of a series-parallel controller (Type K6) of the General Electric Company, are given in Fig. 9.

From these diagrams it is seen that the motors are first

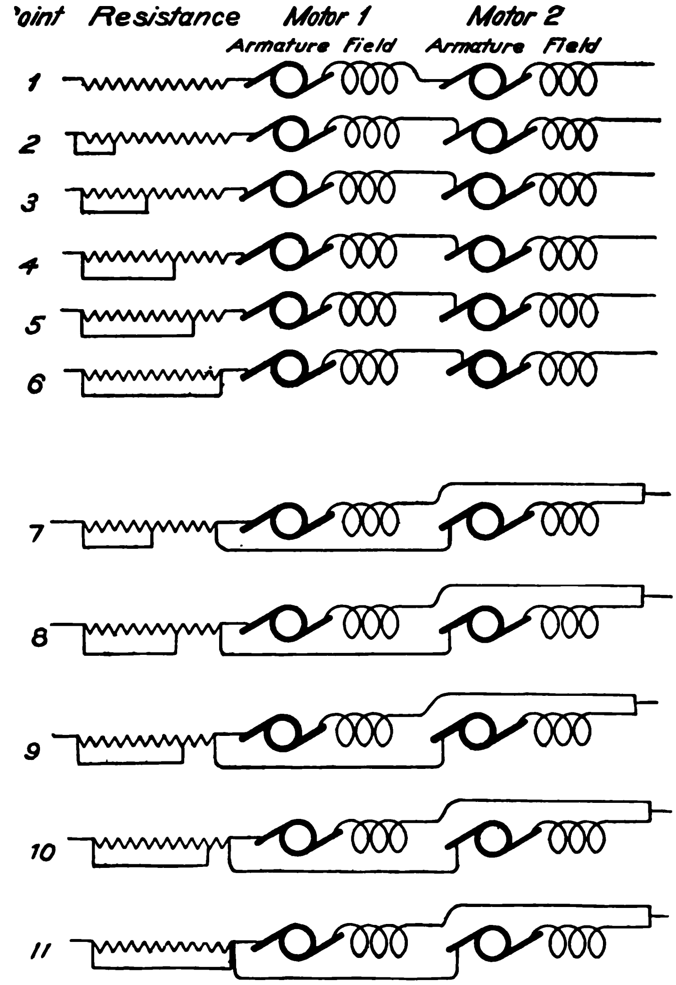


Fig. 9. Diagram of K6 Controller Combinations.

operated in series until all the resistance is short-circuited by the controller. When this has occurred, the cars are running at about half speed. The next point on the controller puts the two motors **in multiple**, with some resistance in the circuit, which resistance is cut out upon the following points, until at full speed the two motors are in multiple, without any resistance in the circuit.

Four Motors. Where four motors are used on a car, as is frequently the case with double-truck cars, the motors on each truck are usually controlled just as in case of the two-motor equipment that has been described; but each pair of motors is operated in multiple. That is, on the first points of the controller, the two motors of a pair are in series, as in Fig. 10, and the two pairs are in parallel; and in the last points of the controller, all the motors are in parallel, as in Fig. 11.

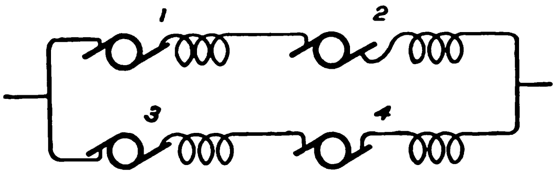


Fig. 10. Motor in Series.

Controller Construction. The controller (Type K) shown open in Fig. 12, which in its various forms is the type most commonly used on street cars in the United States, has a contact cylinder or drum mounted upon the main shaft of the controller. This contact drum carries contact rings insulated from the drum, and is suitably interconnected, as indicated in Fig. 13a, which shows the contact rings of the controller as they would appear if rolled out flat. Contact fingers are placed along the left side of the controller, as seen in Fig. 12, one for each ring on the drum; and as the controller handle is turned to revolve this drum, the contact fingers make contact with the rings on the drum and give the various connections. Alongside the main controller drum is a reverse drum which simply reverses the armature connections of the two motors.

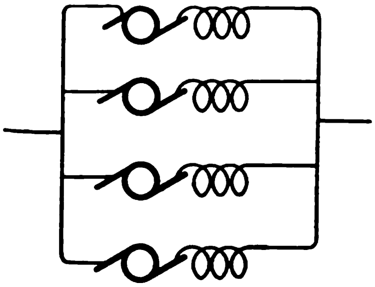


Fig. 11. Motor in Parallel.

Controller Wiring. The connection between motors, controllers, and resistances, with two motors and a K6 controller is

Car Wiring for K-6 Controllers with two Motors
Ground Return System

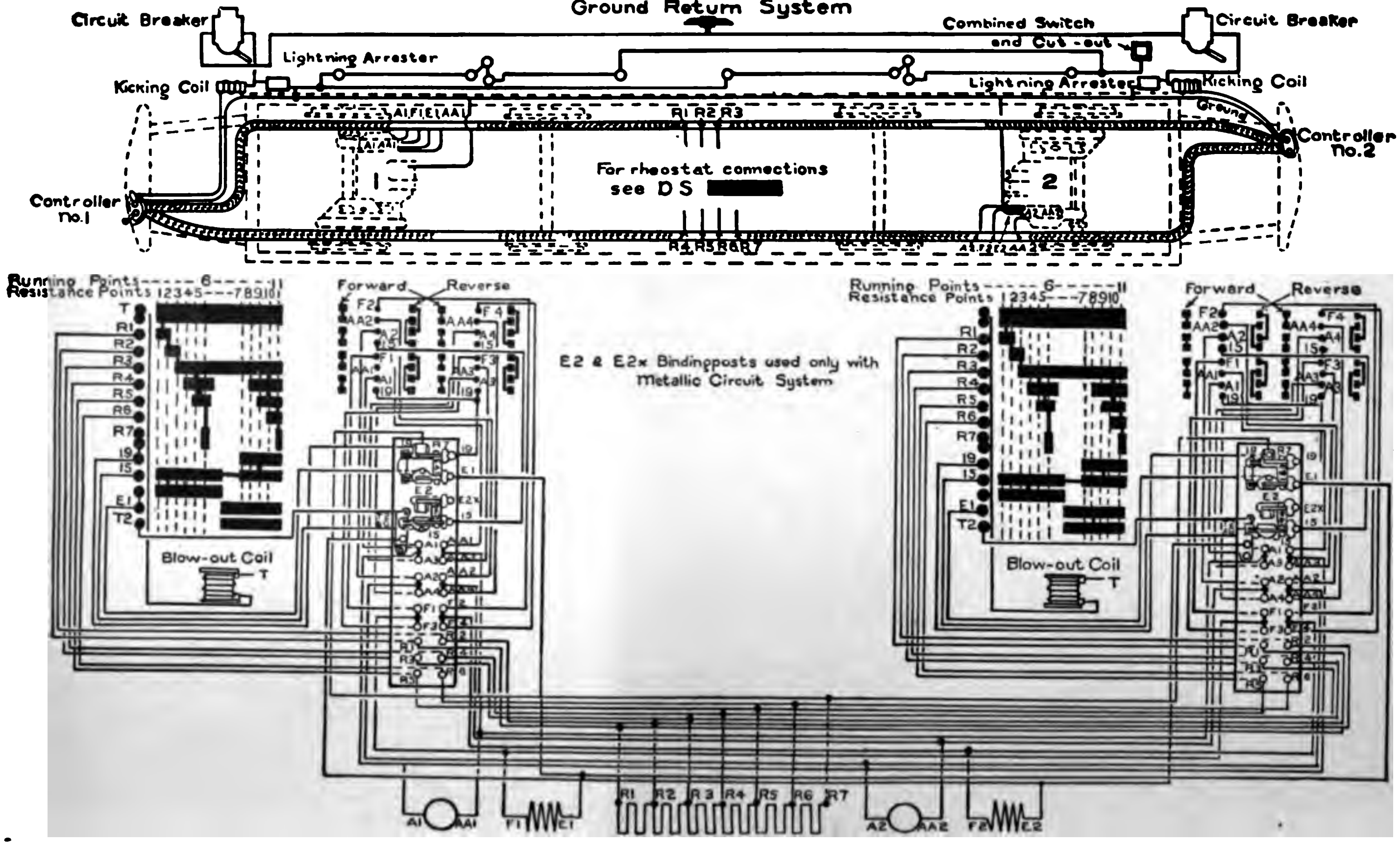


Fig. 136

shown in Fig. 13*a*. A careful study of this will show the combinations to be the same as indicated in the diagram, Fig. 9. The wiring is rather complicated; and in practice, to avoid confusion, the ends of each wire are labeled with tags showing the terminals to which they belong.

Reversal. The reversing handle and the main controller handle are made interlocking so that the motors cannot be reversed without first throwing the controller to off position. This is to prevent damage to the motors through careless or inadvertent throwing of the reverse handle when the controller is on some of its highest points. Such a reversal would cause an enormous current to flow through the motors, and would be likely to damage them and to open all the circuit-breakers and fuses in that circuit. The reason for the enormous flow of current is, of course, that the counter-electromotive force of the motors when reversed with the

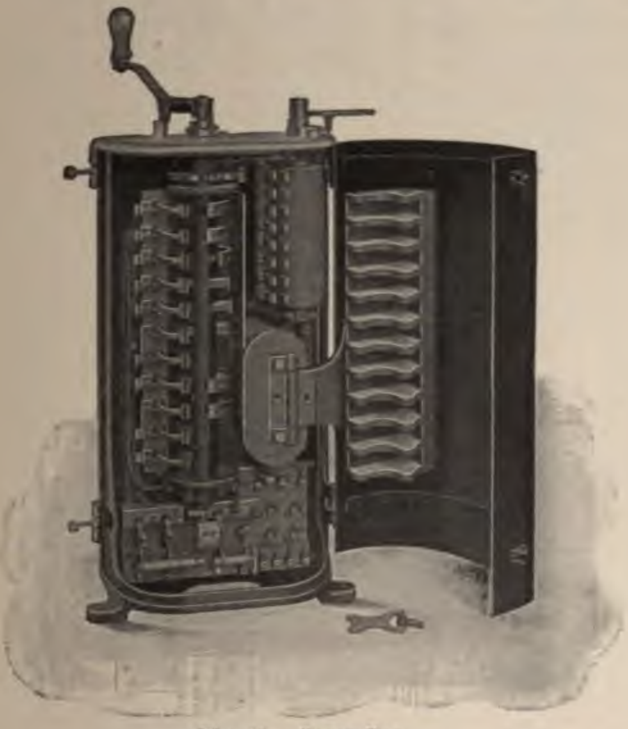
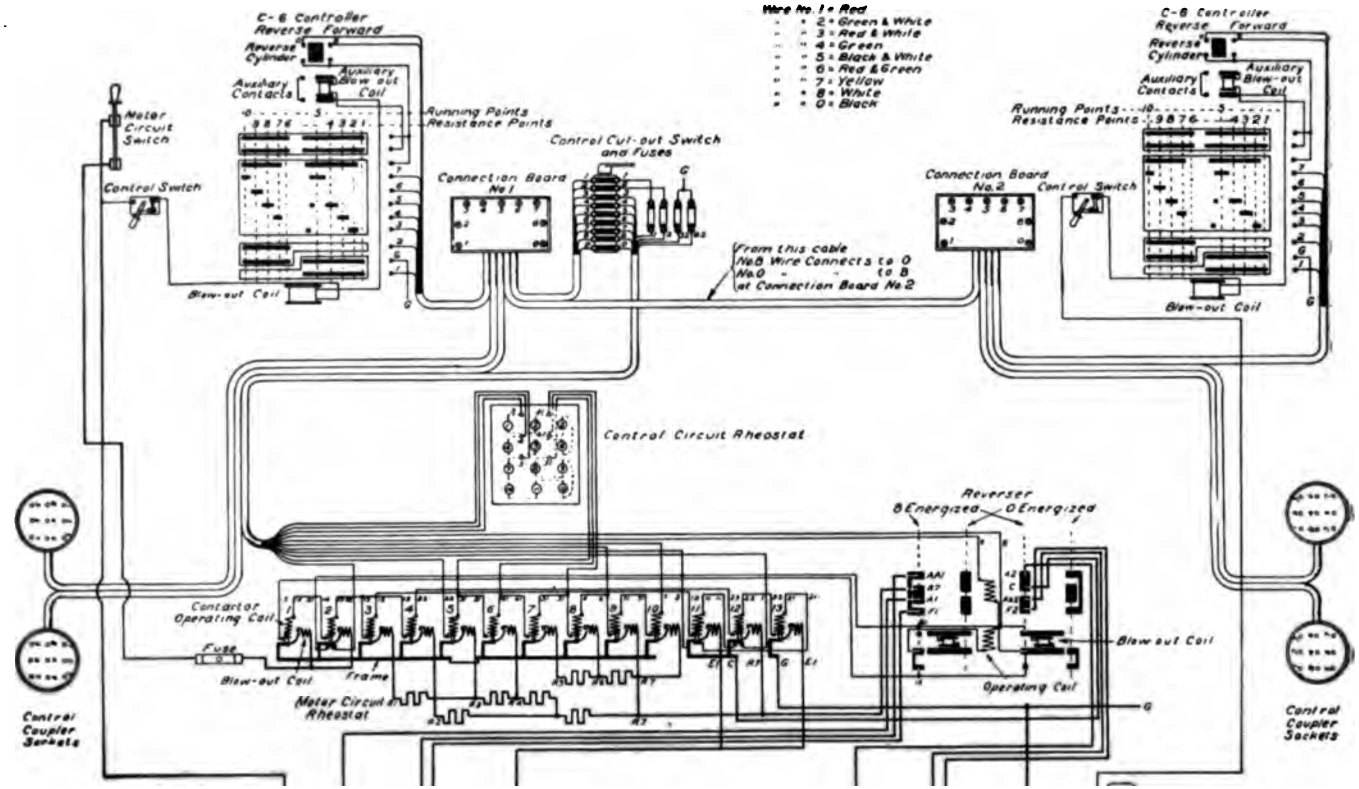


Fig. 12. Controller.


C-6 Controller
Reverse Forward
Reverse Cylinder
Auxiliary Contacts
Auxiliary Blow-out Coil
Running Points
Resistance Points
Blow-out Coil
Motor Circuit Switch
Control Switch
Connection Board No. 1
Control Cut-out Switch and Fuses
G
Wire No. 1 = Red
" " 2 = Green & White
" " 3 = Red & White
" " 4 = Green
" " 5 = Black & White
" " 6 = Red & Green
" " 7 = Yellow
" " 8 = White
" " 0 = Black
From this cable No. 8 Wire Connects to 0
No. 0 " " to 8
at Connection Board No. 2
Connection Board No. 2
Control Switch
C-6 Controller
Reverse Forward
Reverse Cylinder
Auxiliary Contacts
Auxiliary Blow-out Coil
Running Points
Resistance Points
Blow-out Coil
G
Control Circuit Rheostat
Reverser
8 Energized
0 Energized
Contactor Operating Coil
Fuse
Blow-out Coil
Frame
Motor Circuit Rheostat
Blow-out Coil
Operating Coil
G
Control Coupler Sockets
Control Coupler Sockets

car going at some speed would materially add to the electromotive force of the trolley line, instead of opposing it as when the cars are in operation. The current flowing through the motor circuit would then be equal to (*electromotive force of line + electromotive force of motors*) ÷ (*resistance of motors*,) which would result in a very large current.

Magnetic Blow-Out. On the Type K controller as well as on most other successful controllers, the flashing or arcing between contact rings and fingers which occurs when the circuit is broken, is materially reduced by a magnet that produces what is called the magnetic blow-out to extinguish the arc. This magnet derives its current from the main circuit, and is so arranged as to create a strong magnetic field in the neighborhood of the place where the arc is formed. Fig. 12 shows a Type K controller open with the magnetic blow-out magnet thrown back on a hinge. The coil which produces this magnet is seen in the right side of the controller. The main contact drum is in the middle, and the reversing drum at the right hand. There are in use a number of other controllers built upon these same general principles but differing in mechanical arrangement.

Controller Notches. All controllers are provided with some device which prevents the motorman from stopping the controller handle between the various points or notches, as the stopping between points might result in drawing an arc or an imperfect contact. The most common arrangement to prevent this is a notched wheel on the controller shaft, against which bears a small wheel of just the right size to enter the notches. The small wheel is held against the notched wheel by a strong spring. As the tendency of the small wheel is to seek the bottom of the notches, it is difficult to stop the controller handle anywhere between notches, and the motorman is thus given a guide which tells him without any effort on his part just where the notches are.

A switch is usually provided in a controller, for cutting out of service one motor or a pair of motors if defective, and allowing the car to proceed with the good motor or motors.

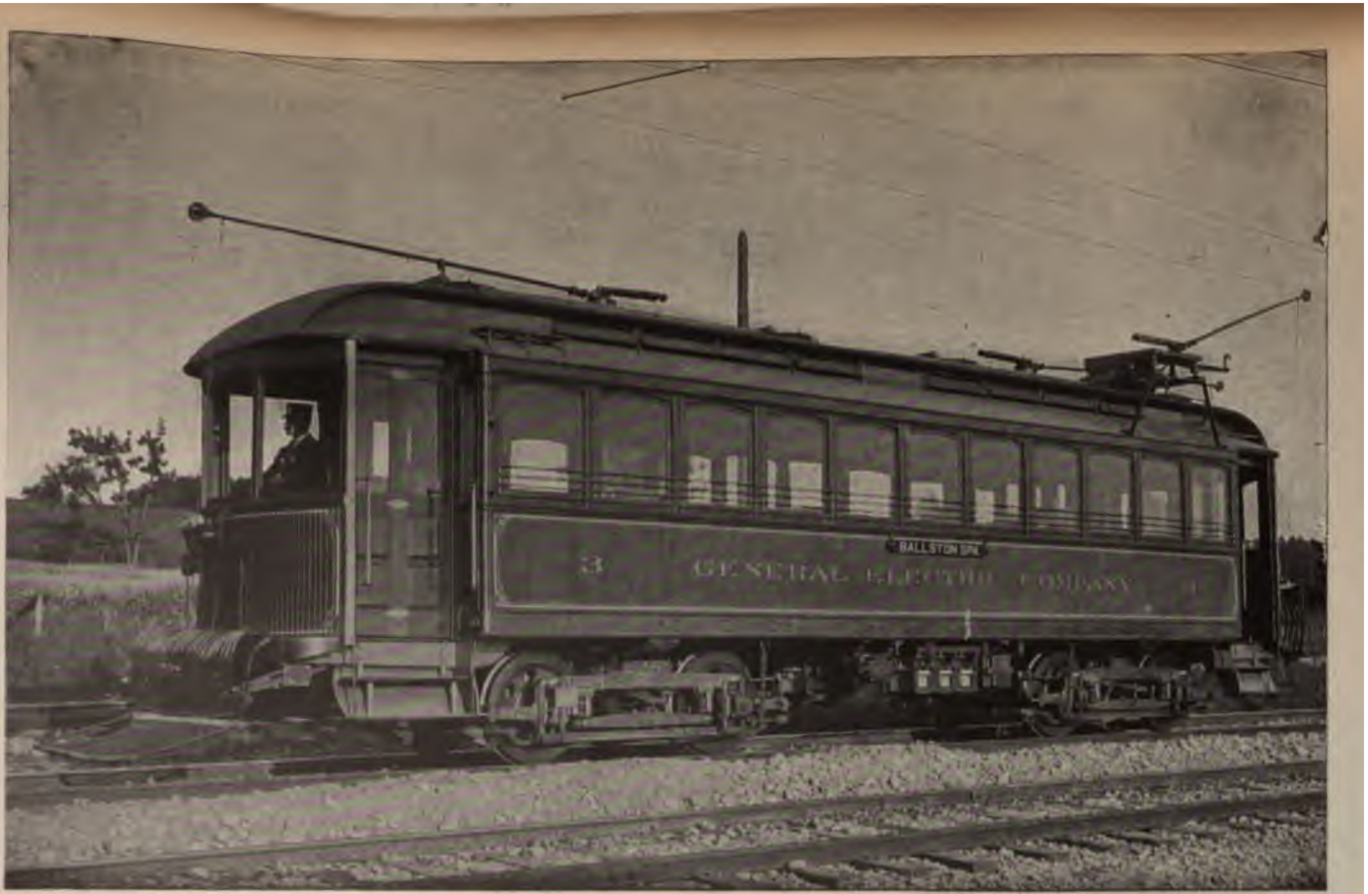
Multiple-Unit Control. A system called "multiple-unit control" or "train control" has come into use where it is desired to operate motors under a number of different cars in a train; all t motors being controlled from the head of the train or from any other point on the train where the motorman may be stationed.

There are several types of multiple-unit control. In all of them there is on each car a controller of some kind which controls the current flowing to the motors on that car. This controller is operated from a distance by means of electro-magnetic or electro-pneumatic devices controlled by circuits called **pilot circuits**, which circuits are connected to the motorman's controller. All the pilot circuits of a train are connected together by means of train plugs which make the connections between the cars. The pilot circuits of each car are connected to a motorman's controller on that car and this makes it possible to operate the train from any controller

Sprague Multiple-Unit System. In the earliest form of multiple-unit control—which was that devised by F. J. Sprague—the motors on each car were controlled by an ordinary Type K controller, which had geared to its shaft a small pilot motor. The pilot motor was controlled by the pilot circuits connected with the motorman's controller.

In the more recent forms of multiple-unit control, the use of main controllers having contact cylinders has been practically abandoned. The contacts are made instead by a number of electro-magnetic or electro-pneumatic contact devices sometimes called **contactors.**

General Electric Train Control. In the General Electric train-control system each contact for the motor circuits is made by a solenoid magnet which draws together two heavy copper contact fingers to establish the circuit. A magnetic blow-out coil in series with the contact is also provided. The contactors make contact only when energized by a small amount of current from the master or motorman's controller. In Fig. 13*b* is a diagram of the car wiring for a motor car equipped with this system. The motorman's controller is a drum controller, but is comparatively small since it has to handle only the small amount of current necessary to operate the solenoid magnets of the contactors. It is evident that by connecting together the pilot circuits, which are connected to the motorman's controller, so that the pilot circuits will be continuous for the entire length of the train, any number of cars equipped with the train-control system can be



ALTERNATING MOTOR CAR.

General Electric Company.

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TILDEN FOUNDATIONS

operated; and similar contacts will be made by the contactors under all the cars simultaneously, by virtue of the circuits established by the master controller at any platform.

Besides controlling the contactors, the master or motorman's controller must control an electro-magnetic reversing switch, or **reverser**, to change the direction of car travel.

The handle of the motorman's controller is provided with a push button, which must be depressed while the current is turned on. Should the motorman release this push, the circuit through the controller will be opened and all the contactors will fall open. This handle is called the **dead man's handle** because it is put there to provide for cutting off the current should the motorman fall dead or in a faint at his post.

CAR HEATERS.

Electric Heaters for warming cars in winter, consist of iron wire coils which are warmed by the passage of electric current through them. The heat so evolved varies as the resistance multiplied by the square of the current. The iron wire coils of the heater are mounted on non-combustible insulating supports, and are arranged so that there is a free circulation of air through them. The coils are surrounded with a perforated metal case, the object of which is to prevent injury to the coils and to prevent persons or clothing coming in contact with the hot, live wires of the coils. Heaters are frequently arranged so that they can be connected in series or parallel to give different degrees of heat.

Hot-Water Heaters are frequently used on large electric cars. Hot-water pipes are placed along the sides of the car, and connected with a stove containing hot-water coils at one end of the car. The water, as it is heated in the stove or heater, expands, and consequently becomes lighter per cubic inch or other unit of volume; it therefore tends to rise when balanced against the colder water in the car pipes. Hot water leaves the top of the heater, flows down through the car piping, and back to the bottom of the heater. The car piping slopes continuously down from the top connection to the bottom connection of the heater. At the top, an opening to the atmosphere is provided through a small water tank, called an **expansion tank**. This prevents water pressure bursting the pipes as they become heated, and allows any steam that may have formed to escape. The most modern hot-water heaters for cars are completely closed except as to the ash-pit at the bottom and a small feed-door in the top. The latter is locked so that the fire cannot come out even if the car is tipped over in a wreck.

CAR WIRING.

The wires from motors to controllers, when placed in exposed position under the car, are bunched in cables or covered with hose. In some cases special runways are provided in the bottom of the car to accommodate the car wiring. All the wiring in a car should be heavily insulated with moisture-proof rubber-covered wire, and further protected from mechanical abrasion by a tough outer covering.

RESISTANCES.

The type of resistance now most common for heavy motor equipment is in the form of cast-iron grids, which are assembled together and connected in series. These grids are sufficiently stiff to render unnecessary any solid insulation between them, and hence they can radiate heat to the best advantage The only difficulty experienced with them is from the warping or cracking. Resistances for lighter equipment are composed of sheet-steel ribbons wound in coils. Each turn of a coil is insulated from the next by asbestos. Other forms of sheet-steel resistance with asbestos insulation between the turns, have also been used.

ELECTRIC CAR ACCESSORIES.

Canopy Switch. An overhead switch, sometimes called a "canopy switch," is commonly placed over each street-car platform where a controller is located, usually in the deck or canopy above the motorman's head. This is simply a single-point switch that may be used by the motorman to cut the trolley current off from the controller wiring so that the controllers will be absolutely dead. When two such switches are used, one on each end of the car, they are connected in series.

Car Circuit Breaker. Frequently on large equipments an automatic circuit-breaker is provided instead of this overhead switch. This circuit breaker can be tripped by hand to open the circuit whenever desired; and is also equipped with a solenoid magnet, which can be adjusted so that it will trip or open the circuit-breaker at approximately whatever current it is set for. This circuit-breaker protects the motor and car wiring from excessive current, such as would occur in case of a short circuit in motors or car wiring, or in case the motorman turned on current so rapidly as to endanger the windings of the motors. When circuit-breakers are used at each end of a car in place of the canopy switch, they should be connected in multiple; one to each controller, but the trolley terminals of the two controllers should not be connected together. The entire current will then flow through the circuit-breaker at the motorman's end of the car. Otherwise, the two circuit-breakers would divide the current between them. Circuit-breakers, however, are most commonly used on cars having controllers located at only one end in a motorman's cab.

Fuses. A fuse is placed in series with the motor circuit before it enters the controller wiring, but where circuit-breakers are used instead of canopy switches, the fuse-box may sometimes be dispensed with. The fuse-box on street cars is usually located underneath one side of the car body where it is accessible for replacing fuses, but where a motorman's cab is used, the fuse may be placed in the cab. The fuse may be of any of the types in common use, either open or enclosed. In the Westinghouse fuse box it is necessary only to open the box and drop in a piece of straight copper wire of the right length and size. The closing of the box clamps this wire to the terminals and establishes a circuit through the copper wire as a fuse. Of course this copper wire is of small enough size to be fused by a dangerously heavy current.

Lightning Arresters. A lightning arrester is used on all cars taking current from overhead lines. The lightning arrester is connected to the main circuit as it comes from the trolley base, before it reaches any of the other electrical devices on the car, so that it may afford them protection. One terminal of the lightning arrester is connected to the motor frame so as to ground it, and the other is connected with the trolley. In most forms of lightning arrester, a small air-gap is provided, not such as to permit the

500-volt current to jump across, but across which the lightning will jump on account of its high potential. To prevent an arc being established across the air-gap by the power-house current after the lightning discharge has taken place and started the arc, some means of extinguishing the arc is provided. In the General Electric Company's lightning arrester, the arc is extinguished by a magnetic blow-out, which is energized by the current that flows through the lightning arrester. The instant the discharge takes place the current flows across the air gap. The magnetic blow-out extinguishes the arc, and this opens the circuit, leaving the arrester ready for another discharge. In the Garton-Daniels lightning arrester a plunger contact operated by a solenoid opens the circuit as soon as current begins to flow through the arrester. This plunger operates in a magnetic field, which extinguishes the arc. A choke coil, consisting of a few turns of wire around a wooden drum, is placed in the circuit leading to the motors at a point just after it has passed the lightning arrrester tap. This choke coil is for the purpose of placing self-induction in the circuit, so that the lightning will tend to branch off through the lightning arrester and to ground, rather than to seek a path through the motor insulation to ground.

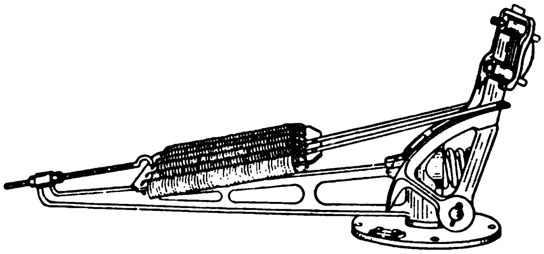

Fig. 14. Trolley Base.

Lamp Circuits. The lamp circuit of a car is protected by its separate fuse-box, and usually each lamp circuit has a switch. As explained before, five 100-volt or 110-volt lamps are placed in series between the trolley wire side of the circuit and ground. If one lamp in the series burns out, of course, all five are extinguished until the defective lamp is replaced with a new one. Enclosed arc lamps are sometimes used for car lighting.

Trolley Base. The trolley base upon which the trolley pole swivels, and which furnishes the tension that holds the trolley wheel against the wire, is designed to maintain, by means of springs, an approximately even tension against the trolley wire, whether the trolley wire is high above the track or near the car roof. This is done by changing the relative leverage which the springs of the trolley base have on the trolley pole according to the height of the trolley pole.

Fig. 14 shows one form of trolley base. The trolley base is bolted to a platform constructed for it on the roof of the car; and the supply wire to the motors and other electrical devices on the car, except in cases where a wooden trolley pole is used for certain special reasons, is connected directly to the trolley base. An insulated trolley wire is run down the wooden trolley pole, and connected through a flexible lead to the car wiring.

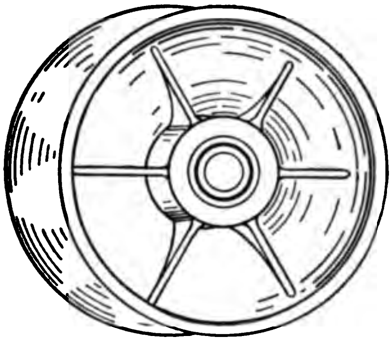

Fig. 15. Trolley Wheel.

Trolley Poles. The trolley poles in general use are of tubular steel, which gives the greatest strength for a given weight, and which can usually be straightened if the pole has been bent by striking overhead work when the trolley wheel leaves the wire.

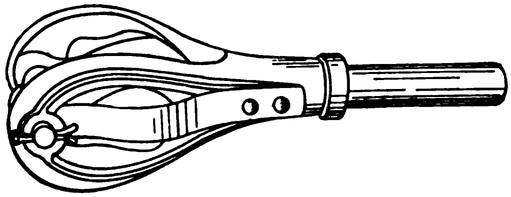

Fig. 16. Trolley Harp.

Trolley Wheels. Trolley wheels are from four to six inches in diameter over all, the small wheels being used in the city service, and the large wheels in high-speed inter-urban service. A typical trolley wheel is shown in Fig. 15. Various companies use various forms of groove in the trolley wheels, some adopting a groove approximately V-shaped. The U-shaped groove, however, is the most common, The trolley wheel is made of a brass composition selected for its toughness and wearing qualities.

Trolley Harp. The trolley harp, which is placed on the end of the trolley pole and in which the trolley wheel revolves, usually has some means for making electrical contact with the wheel in addition to the journal bearing. In the harp illustrated in Fig. 16, which is a typical form, this additional contact is secured by a spring bearing against the side of the hub of the wheel.

Since trolley wheels revolve at a very high speed, some unusual means of lubrication must be provided, since there is no opportunity for ordinary oil or grease lubrication. Graphite, in the shape of what is called a "graphite bushing," is most commonly used. This is a brass bushing, which is pressed into the hub of the trolley wheel. In this bushing is a spiral groove filled with graphite which is supposed to furnish sufficient lubrication as the bushing wears. Roller-bearing trolley wheels have been used to a limited extent, with considerable success in some cases. Some companies have done away with the graphite bushing, and have provided a very long journal for the trolley wheel instead of the usual short bushing.

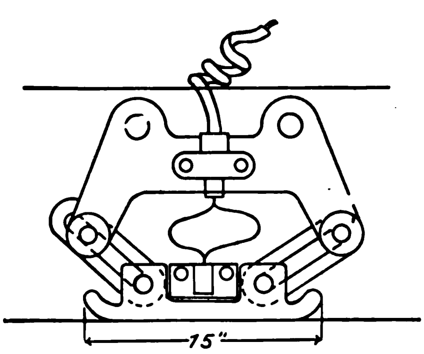

Fig. 17. Third Rail Shoe.

Contact Shoes. The contact shoe most commonly used on roads employing the third rail is shown in Fig. 17. This is simply a shoe of cast iron hung loosely by links. The weight of the shoe is sufficient to give contact. The motion of the links permits the shoe to accommodate itself to unusual obstructions and variations in the height of the third rail. The shoe is fastened to the truck frame by means of a wooden plank which furnishes the necessary insulation.

The Potter third-rail shoe which has been used to a limited extent, employs a spring for giving the necessary tension to make electrical contact between the shoe and the third rail. In some ways this is superior, because a spring tension is quicker in its action than gravity, and the shoe accommodates itself better to variations in the height of the third rail at very high speed. The wear on the shoe, however, is likely to be greater.

TRUCKS.

Electric railway cars are classified generally as **double-truck** and **single-truck cars**. Double-truck cars are those that have a truck that swivels at each end of the car. A single truck car is one having four wheels.

Single Trucks. A great many types of single trucks have been designed. It would be out of the question to discuss them all here. In general, however, it may be said that truck builders have aimed to make a truck frame in itself a complete unit independently of the car body, so that the car body will simply rest upon the trucks and there will be no strain on the car body in maintaining the alignment of the truck. Most single trucks, therefore, consist of a rectangular steel frame, either cast or forged, riveted or bolted together. This frame holds the journal boxes in rigid alignment. Usually a spring is placed between each journal box and the truck frame. This spring may be either spiral or elliptic.

The principal springs, however, are between the truck frame and the car body. Most truck builders have used a combination of spiral and elliptic springs between the car body and qualities and greater freedom from teetering or galloping than either spiral or elliptic springs alone. Fig. 18 shows a Brill single truck, which illustrates all of the features enumerated.

Swivel Trucks. Swivel trucks, commonly called **double trucks**, are made in many forms, but the most common is that popularly known as the M. C. B. type of truck. This truck is similar to the standard truck which is in universal use on steam railroad passenger cars in the United States. Different on steam railroad passenger cars in the United States. Different truck builders have introduced many variations in this general type of truck, in adapting it to electric service. Some modifications from the steam railroad standard truck were neces

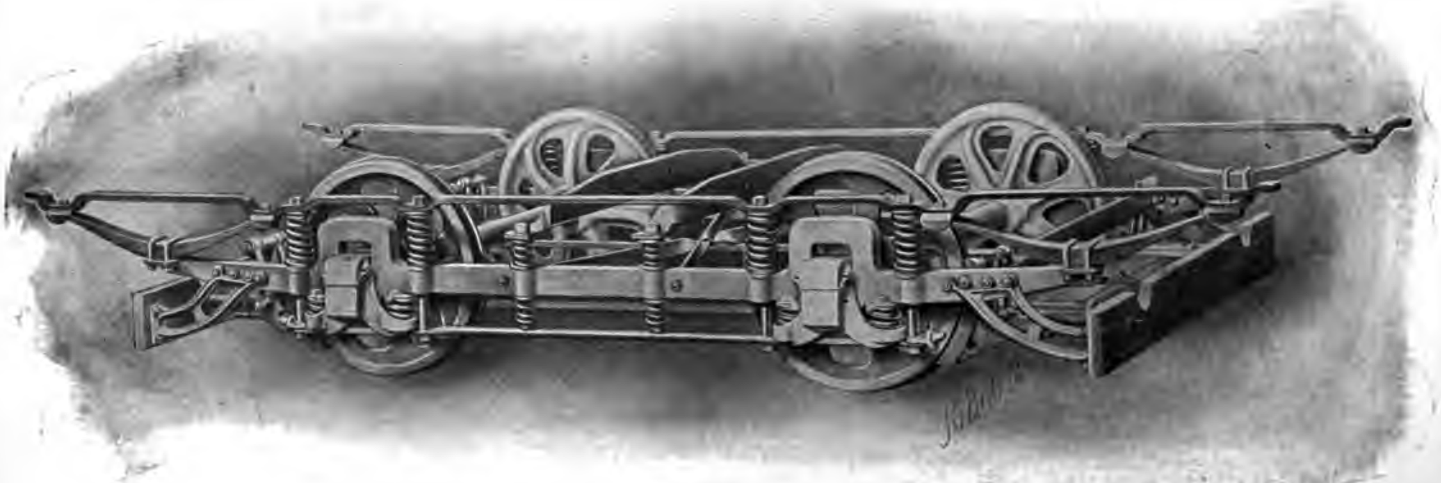

Fig. 18. Brill 21-E Car Truck.

accommodate the electric motors and to permit in some cases a low-hung car body. Such trucks are made in a great variety of sizes.

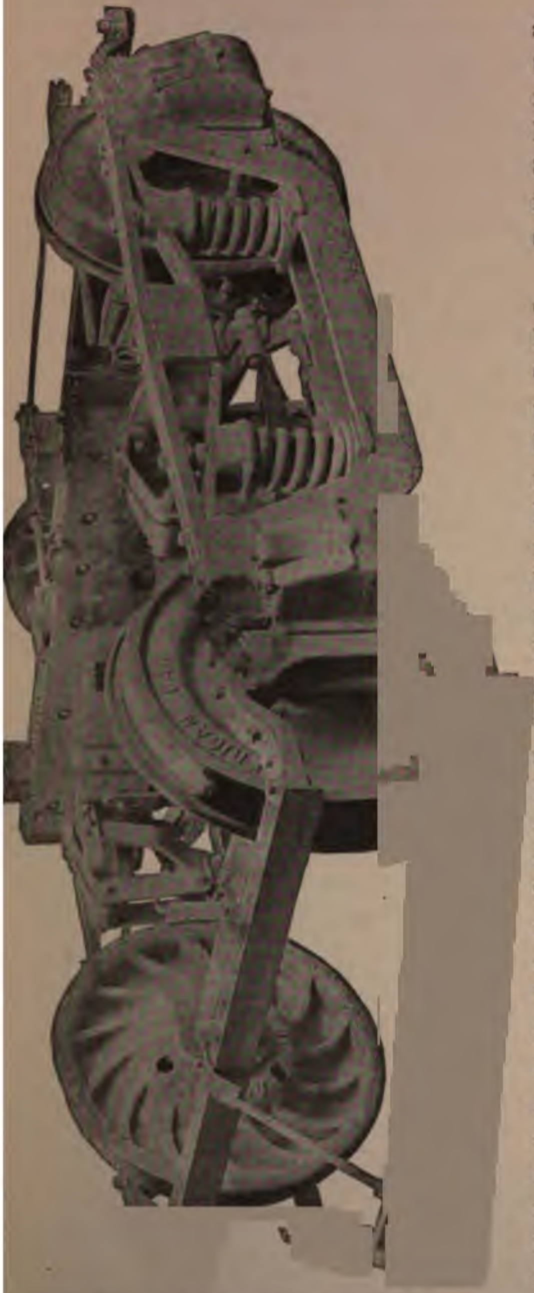

Fig. 19. St. Louis Car Company Truck.

Fig. 19 shows one of these trucks built by the St. Louis Car Company. In this type of truck the car body is fastened to the truck only by the kingbolt on which the truck swivels. This kingbolt is placed in the center of the truck bolster. There are also side bearings between the car body and the ends of the bolster, to prevent tipping of the car body when it is unbalanced. The arrangement of this part of the truck is shown in Fig. 20. Under this bolster are elliptic springs which rest on what is called **spring plank.** This spring plank is hung from the rectangular frame of the truck by links which allow a side motion. This side motion gives easier riding, especially upon entering and leaving curves. All trucks having this feature are known as **swing bolster trucks.** The weight, being transmitted to the transom and truck frame through the swinging links just referred to, is then taken by the equalizer springs that support the rectangular truck frame on equalizing bars, which equalizing bars rest on the journal box at either end and are bent down to accommodate the springs located between them and the truck frame. The truck frame holds the journal boxes in alignment by means of guides which permit an up-and-down movement without movement in any other direction, just as on all other types of truck. It is thus seen that there are two sets of springs between the car body and car journals; one set of spiral springs between the equalizing bar and truck frame; and one set of elliptic springs between the spring plank and the bolster. All shocks must be transmitted first through the spiral springs and then through the elliptic springs. The motors used on this type of truck usually have nose suspension, the nose of the motor resting either on the bolster of the truck or on the truck frame.

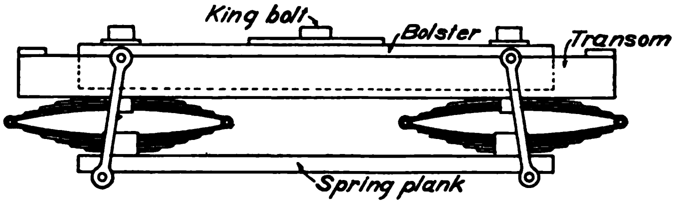

Fig. 20. Bolster, Links and Spring Plank.

There are a number of swivel trucks made which have departed considerably from M. C. B. lines but nearly all retain the features of a bolster mounted by springs on a spring plank, a spring plank hung from a transom, a transom rigidly fastened to the rectangular truck frame of which it forms a part; and a truck frame with one or more sets of spiral springs between it and the journal boxes.

Maximum Traction Trucks. A type of swivel truck that once was very popular but has largely been superseded by the type just described is the "maximum traction truck." This truck has two large wheels on an axle which carries 60 to 70 per cent of the weight on the truck, and two small wheels carrying the balance of the weight. The motors are on the large wheels.

Car Wheels. The car wheels most commonly used are of cast iron. In order to make a tread and flange upon which the wear comes hard enough to give a good mileage, the tread and flange are chilled in the process of casting. Around the periphery of the mould in which wheels are cast, is a ring of iron instead of the usual sand. When the molten cast iron comes in contact with this ring of iron, which is called a "chill," the iron is cooled so suddenly that it becomes extremely hard. The balance of the wheel, cooling more slowly since it is surrounded by sand, has the hardness of ordinary cast iron.

Wheels with steel tires are coming into use for elevated and inter-urban cars because their flanges are not so brittle as those on cast-iron wheels. In wheels of cast metal there is always a liability that the flanges and tread will chip and crack. On high-speed cars the falling-out of pieces of flange may be a serious matter and result in a wreck. Steel-tired wheels have a hub and spokes either of cast or forged steel or iron. On to this wheel a steel tire is shrunk. The tire is first heated in a furnace built for the purpose, and is then slipped over the wheel. It is made just such a size that it will slip over the wheel when hot, and when it is cool it will shrink enough to make a very tight fit. When the tire is to be removed after it is worn out, it is heated until it has expanded sufficiently to drop off.

When cast-iron wheels are worn to an improper shape or have flat spots upon them, due to the sliding of the wheels with the brakes set, an emery wheel grinder must be used to grind them down, as nothing else is hard enough to have any effect on the iron.

When steel-tired wheels are worn, they can be put in a lathe and the surface of the tire turned off, as this surface is of metal soft enough to be workable with ordinary tools.

The types of wheel tread and wheel flange in use vary greatly among different electric railways. There is a standard Master Car Builders' wheel tread used on steam railroads, which is shown in Fig. 21. Electric railways, however, are usually obliged to use a smaller flange and narrower tread. Street railway special work, such as switches and crossings, usually has too shallow a flange way to permit a standard M. C. B. flange to pass through. Some street railways use flanges as shallow as ⅜ inch, although ¾ inch is most common on city work. The width of the tread on street railway cars, that is, the width of the wheel where it bears on the rail, is usually from 1¾ inches to 2¼ inches. There is a tendency, however, on electric railways, on account of the increasing number of inter-urban cars which must use city tracks, to build tracks that will accommodate wheels approaching the M. C. B. standard of steam roads. A few roads have adopted wheel treads and flanges very near to the M. C. B. standard.

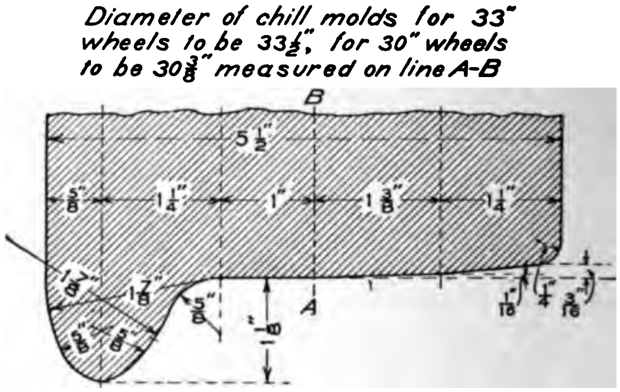
Diameter of chill molds for 33" wheels to be 33½", for 30" wheels to be 30⅜" measured on line A-B
B
5½"
⅝"
1¼"
1"
1⅜"
1¼"
1⅞"
1⅞"
⅝"
⅝"
⅝"
⅝"
⅝"
A
1/16"
¼"
3/16"

Fig. 21. Standard M. C. B. Flange.

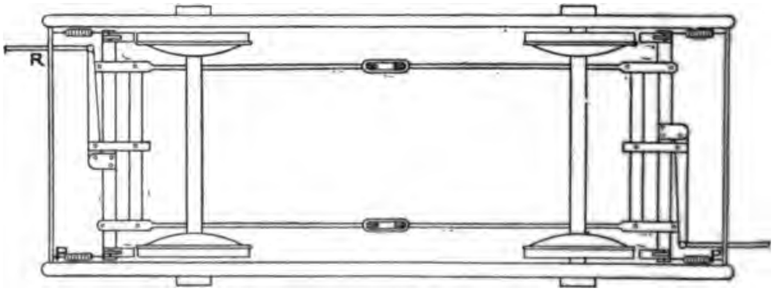

Fig. 22. Brake Shoes and Levers.

Brake Rigging. The brake rigging on a single-truck car may be arranged in a variety of ways, but should always cause a nearly equal pressure to be brought to bear on the brake shoes on all four wheels. A typical arrangement of brake shoes and levers for single-truck cars is shown in Fig. 22. The rods R terminate in chains winding around the brake staff upon which the motorman's handle or hand wheel is mounted.

For double-truck cars the brake rigging is necessarily more complicated, as it must be arranged to give an equal pressure on all eight wheels of the car. Brake shoes are sometimes placed between the wheels of a truck and sometimes outside. The arrangement of brake shoes between wheels is apparently finding most favor, as when the shoes are applied in this position there is less tendency to tilt the truck frame when the brakes are applied, and this adds to the comfort of passengers in riding. Fig. 23 shows one form of arrangement of brake levers common on a double-truck car equipped with air brakes, with inside-hung brake shoes.

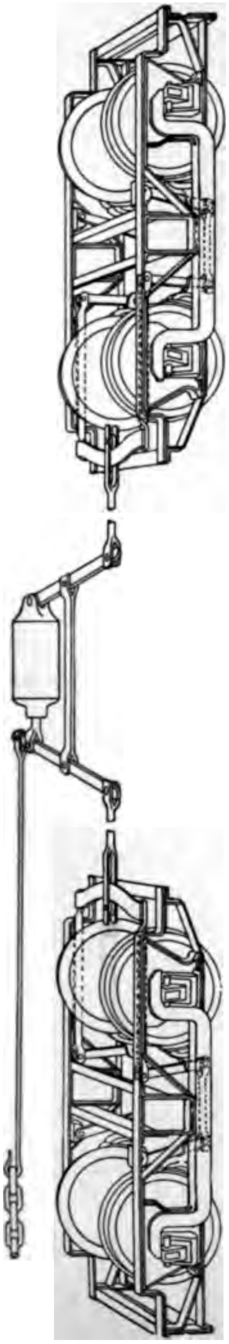

Fig. 23. Brake Levers and Air Brake.

Air Brakes. Air brakes used on electric railway cars are usually of what is called the **straight air brake** type in distinction to the **Westinghouse automatic air brake.** A straight air brake is one in which the air is stored in a reservoir; and, when the brakes are to be applied, air from this reservoir is turned directly into the brake cylinder, in which works a piston operating the brake levers. Air admitted behind the piston forces it out with a pressure which applies the brakes. When the air is let out of the brake cylinder, a spiral spring forces the piston back to its original position and the brakes are released. The motorman's valve by which he applies the brakes, therefore, provides, first, for turning air from the storage reservoir to the brake cylinder to apply the brakes, and, second, for closing the opening to the storage reservoir and opening an exhaust passage from the brake cylinder so that the air can escape from the brake cylinder to release the brakes.

Straight air brakes of this kind would not be suited to the operation of long trains, because, if the air-brake hose connection between cars should be broken, the brakes would be useless; but for trains of one or two cars, such as are common in electric railway practice, the simplicity of the straight air brake, outweighs its disadvantages and this is the type of brake usually employed.

The Westinghouse and other forms of automatic air brake are used on electric railways where cars are operated in long trains; but it is out of the province of this paper to describe these brake systems fully, as they are rather complicated. It may be said in general, however, that the Westinghouse automatic air brake is so arranged that, should the hose connection between cars be broken, should the train pull in two, or should anything happen to reduce the pressure which is maintained in the train pipe that runs the length of the train, the brakes would immediately be applied on the entire train.

Compressors. A small air compressor driven by an electric motor is frequently employed on electric cars to keep the storage reservoir of the car supplied with air. These air compressors are carried under the car or in the motorman's cab. They are generally arranged with an automatic device which closes the motor circuit and starts the motor as soon as the air pressure falls below a certain amount ; and the motor will continue in operation pumping air until the pressure rises to the amount for which the automatic device is set. The pressure carried in the storage reservoir is usually from 60 to 90 pounds per square inch, which, as a general thing, is considerably more than is required to apply the brakes hard enough to slide the wheels.

Storage Air Brakes. The storage air-brake system does not have a small independent compressor on each car, but is equipped with a large storage tank, in which air is carried under high pressure—250 to 300 pounds per square inch. This storage tank is filled at regular intervals when the car passes some point on its route at which a compressor is located. In this case the car is obliged to stop long enough to make connection to the tank of the compressor plant, and to allow the car storage tank to be filled. This operation, however, does not take long. The advantages of the system are a saving of the weight and a saving in the maintenance of a small compressor on each car. From the main storage tank under the car, air is led through a reducing valve to an auxiliary storage tank. This reducing valve allows enough air to pass through to maintain a pressure of about 50 pounds per square inch in the auxiliary storage tank. The auxiliary storage tank corresponds to the regular storage tank on a system employing compressors on each car. The method of operation after the air has entered the auxiliary storage tank is the same with any air-brake system.

Momentum Brakes. Momentum or friction brakes have been used to some extent both on single-truck and on double-truck cars, but particularly on single-truck cars. They derive the power to operate the brakes from the momentum of the car by means of a friction clutch on the car axle. The difference in various kinds of momentum brakes lies chiefly in the design of the clutch mechanism. The clutch must evidently be arranged to act very smoothly, and must be under very accurate control, as the force with which the brakes are applied depends directly upon the pull exerted by the clutch.

In the Price momentum brake a flat disc is cast on the car wheel, which is turned off to a smooth surface. Against this disc a friction clutch acts, which has a leather face. The clutch is operated by a motorman's lever through a set of levers. A small movement in the motorman's lever forces the clutch against the disc on the car axle. The clutch winds up the brake chain, and thus supplies power to apply the brakes.

Other momentum or friction clutch brakes have been devised, most of which also use an application of leather on iron for the clutch, as this has been found to be most reliable, and to be least affected by the grease and dirt that is liable to work in between the clutch surfaces.

G. E. Electric Brake. The General Electric Company's electric brake makes use of current generated by the motors acting as dynamos, to stop the car. In order to accomplish this, a brake controller is provided which reverses the armature connections of the motors, and so connects them to operate as dynamos sending current through a resistance in the circuit; the amount of current flowing and the braking effect depending on the car speed and the resistance. In some forms of brake controller, the two controllers are combined in one cylinder, so that the motorman, to apply the electric brake, simply continues the movement of the handle past the "off" position. In others, the brake-controller drum is separate, but is interlocked with the main controller so that it can be used only when the main controller is off.

However the controller may be arranged, the principle involved is that when the motors are revolving by the motion of the car, and the armature connections are reversed as they would be to reverse the direction of motion of the car, the motors begin to generate current as series-wound dynamos. The amount of current generated and the retarding effect, will depend on two things —namely, the speed of the car, with the consequent electromotive force in the motors, and the amount of resistance in the circuit. The amount of resistance is regulated by the motorman by means of his electric brake controller. The function of the electric brake controller is to reverse the motors and to insert enough resistance in the circuit to make a comfortable stop. This current in the motors acting as dynamos, in itself acts as a powerful brake to retard the motion of the car. In the General Electric type of electric brake, the current generated in the motors, in addition to having this retarding effect in the motors themselves, is conducted to brake discs that act as magnetic clutches against one of the car wheels on each axle. The car wheel has a disc cast upon it, and against this the magnetic disc acts. The magnetic disc contains a coil which is in series in the brake circuit.

In applying an electric brake of this kind, the motorman first puts the controller on a point that inserts considerable resistance in the circuit. When the motors have slowed down, the electromotive force, of course, drops, so that to maintain the same braking current there must be a reduction of the amount of resistance, until, when the car is almost at a standstill, the resistance is nearly all cut out. It might seem at first that the current would die

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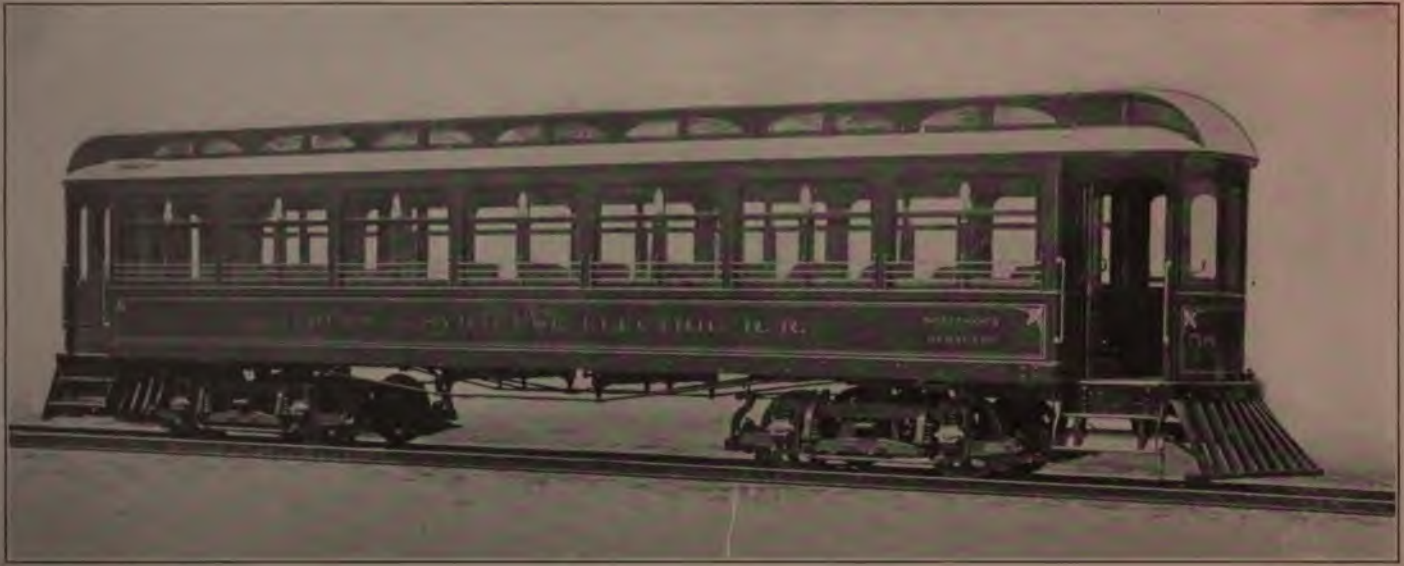

INTERURBAN TYPE OF CAR.

Speed, 60 Miles per Hour.

J. G. Brill Company.

down before the car came fully to a stop, but it is found that there is enough induction in the motor fields to cause current to flow for a short time after the car has stopped. The residual magnetism in the fields is sufficient to cause the motors to begin to generate current when the electric-brake controller is first turned on.
is first turned on.

The greatest advantage of an electric brake using motors as generators, is in the fact that the braking current instantly falls in value as soon as the wheels begin to slide, and releases the brake until the wheels again revolve. In fact, it is almost impossible to skid the wheels by being locked by brake shoes. This not only prevents flat wheels but insures a quick stop, because when the wheels are locked and sliding, the retarding power is only about one-third what it was before the wheels began to slide.

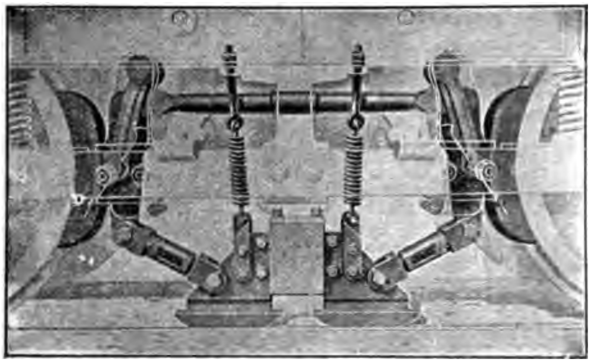

Fig. 24. Magnetic Brake Shoe.

The electric brake requires extra large motors because of the heating caused by the current generated while braking.

Westinghouse Electro-magnetic Brake. The Westinghouse magnetic brake is in principle similar to the General Electric brake as far as the use of motors as generators is concerned; but, instead of assisting the motors by means of a magnetic brake disc acting against the car wheel, a magnetic brake shoe is used (see Fig. 24), which acts against both car wheel and track. This not only retards through the medium of the wheels but acts directly on the track. It is not dependent upon the coefficient of friction between the wheels and track; and it should, therefore, be possible to stop much more quickly than with any form of brake depending upon the coefficient of friction between the wheels and track.

Track Brakes. Track brakes have been used to some extent on very hilly electric roads. These have a shoe fastened to the truck frame, which acts directly on the track.

Coefficient of Friction. It has been found by experiment that the coefficient of friction between the car wheel and rail is about 25 per cent of the weight on the wheel when the rails are dry; that is, a car wheel having a weight of 2,000 pounds upon it would not be able to exert either an accelerating or a retarding force exceeding 25 per cent of this, or 500 pounds. This is when the wheel is rolling. There is apparently a kind of locking or intermeshing of the rough surfaces of wheel and rail when the wheel is rolling, because it is found that when a wheel begins to skid or slide, the coefficient of friction falls off about two-thirds. The maximum braking or retarding force that can be obtained, therefore, in a dry rail, amounts to 25 per cent of the weight of the car. If the rail is slippery this is much reduced; or if the wheels are allowed to slide it is also much reduced. If more retarding force than can be obtained through the medium of a wheel rolling on the rail is desired, it must be obtained either by the track brakes or by magnetism.

Car Bodies. In cities there are three general types in common use; namely, box cars, suited for winter use only; open cars, suited for summer use only; and semi-convertible cars, which can be adapted to either summer or winter use. The open and box cars are the older types. The semi-convertible car is usually provided with a center aisle, and cross seats on each side of this aisle The windows are large, so that they can be lowered or raised in summer to make something approaching the character of an open car. The car bottom, which forms the basis for the entire car structure, is constructed with longitudinal sills either of steel or of wood combined with steel. One form of construction employs as the main supports two steel channel bars extending the full length of the car. Steel I-beams are sometimes used. Where wood is used in combination with steel for longitudinal sills, the steel is usually in the form of flat steel plates between the timbers. Most cars seat about one passenger per foot of length over all.

OVERHEAD CONSTRUCTION.

Trolley Wire. The trolley wire is suspended from the span wires or brackets in such a way as to permit of an uninterrupted passage of an upward pressing trolley wheel underneath it. The trolley wire itself may be either round, grooved, or figure 8 in section. Where a round wire is used, No. 00, B.&S. gage, is the most common size. Figure 8 wire, so called from its section, which is shown in Fig. 25, is designed to present a smooth under-surface to the trolley wheel, which will not be interrupted by the clamps or ears used to support it. Clamps are fastened to the upper part of the figure 8. The grooved wire is rolled with grooves into which the supporting clamps fasten. This wire also presents a smooth under-surface to the trolley wheel.

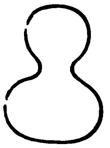

Fig. 25.

Trolley-Wire Clamps and Ears. The trolley is supported either by clamps or by soldered ears. One type of clamp grasps the wire by virtue of screw pressure. A soldered ear is shown at E, Fig. 26. This ear has small projections at each end, which are bent around the wire to assist the solder in holding the wire to the ear. Another form of ear, used to some extent, holds the wire by virtue of having the edges of the groove offset or riveted around the wire.

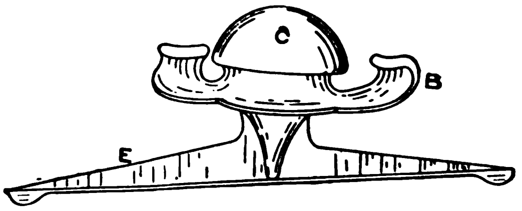

Fig. 26. Trolley Wire Clamp and Ear.

The ear or clamp screws to a bolt which is insulated from the metal ear through which passes the span wire. A cross-section through a common type of trolley-wire hanger is shown in Fig. 27. Here there is an outer shell of metal, which is adapted to hook to the span wire. In this shell is an insulating bolt, that is, a bolt surrounded with some form of insulating material which is very strong mechanically and not likely to be cracked by the hammering action of the passing trolley wheel. Most of the insulating compounds used in making trolley-wire insulators are trade secrets. Another kind of insulator called the "cap and cone" type is shown at C, Fig, 26. In these insulators, the metal part B which fastens to the span wire does not completely surround the insulation C. Wood has sometimes been used for the insulation of trolley-wire hangers.

Span Wires. In city streets, the trolley wire is commonly suspended from span wires stretched between poles located on both sides of the street. These span wires are of $\frac{1}{4}$-inch or $\frac{3}{8}$-inch galvanized stranded steel cable. In order to add to the insulation between the trolley wire and the poles at the side of the street, what is called a **strain insulator** is placed in the span wire. This is an insulator adapted to withstand the great tension put upon it by the span wire. One of these is shown in Fig. 28. Means are usually provided for tightening the span wires as they stretch and as the poles give under the strain. The insulator in Fig. 28 has a screw eye for that purpose.

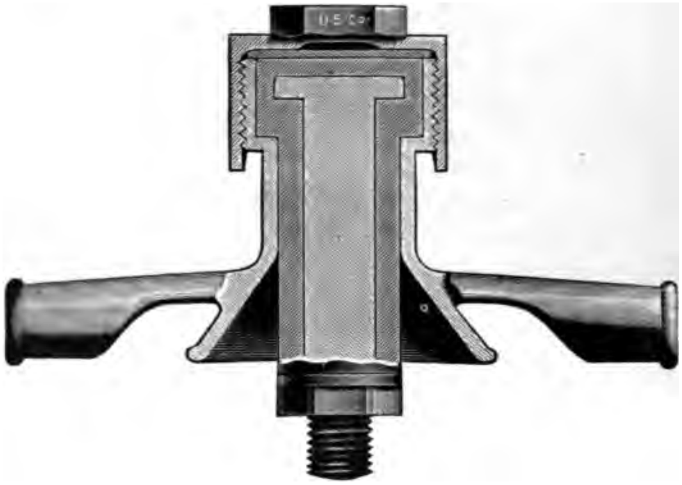

Fig. 27. Cross Section Trolley Wire Hanger.

Brackets. In the bracket type of overhead construction, a trolley wire is fastened to brackets placed on poles near the track This construction is used on suburban and inter-urban lines where the presence of poles near the track is not objectionable. It has been found that a rigid connection of the trolley wire to a bracket is likely to result in the breaking of the trolley-wire insulators. For this reason the brackets now commonly used provide for a flexible suspension of the trolley-wire hanger from the bracket. A bracket employing such flexible construction, made by the Ohio Brass Company, is illustrated in Fig. 29.

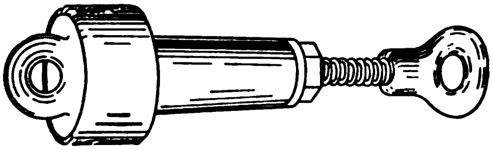

Fig. 28. Strain Insulator.

Feeders. Where additional conductivity is needed beyond that furnished by the trolley wire itself, feeders are run on insulators along the poles at the side of the track. Such feeders are connected to the trolley wire at regular intervals. Where span-wire construction is used, the feed wire may be substituted for the span wire at the pole where the connection between feed wire and trolley wire is made. In such a case, of course, a trolley-wire hanger is used which has no insulator, so that the current feeds directly through the hanger. Another method is to run the feed connection parallel with a span wire and a short distance from it.

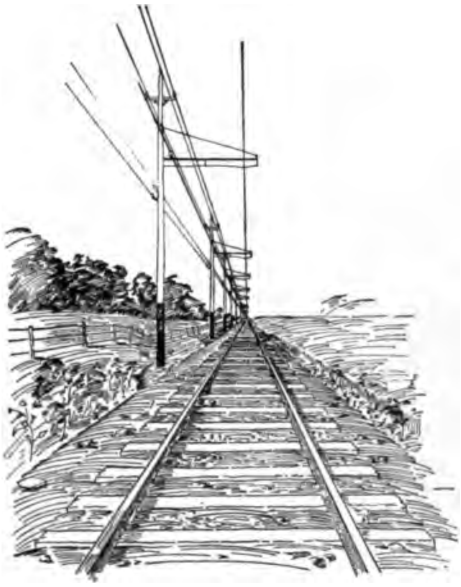

Fig. 29. Overhead Construction.

Section Insulators. Section insulators are usually placed in the trolley wire at regular intervals. Such a section insulator is shown in Fig. 30. Its purpose is to insulate one section of trolley wire from the next, so that in case the trolley wire of one section breaks, or is grounded in any other manner, that section can be disconnected and the other sections on either side kept in operation. In large city street-railway systems, each section of trolley wire usually has its own feeder or feeders, independent of the other sections. This feeder is supplied through an automatic circuit-breaker at the power house. In case a certain section of trolley wire is grounded he large current that immediately flows will open the circuit-breaker supplying that section; but, unless the ground contact is of an extremely low resistance, it will not affect the operation of the other feeders. Should it be of sufficiently low resistance to cause all the generator circuit-breakers to open, it would of course interrupt the entire service temporarily; but usually the circuit-breaker on any individual feeder will cut that feeder out before all the circuit-breakers will open.

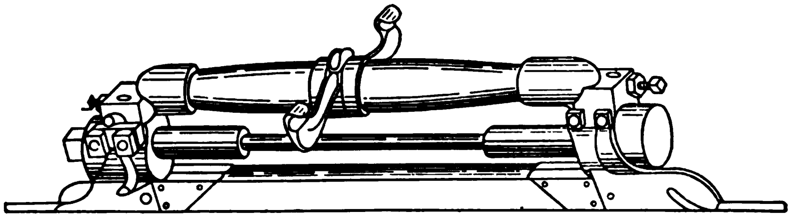

Fig. 30. Section Insulator.

High-Tension Lines. Where high-tension alternating-current wires are run, as in the case where the road is of such length as to require the establishment of several sub-stations, these high-tension circuits are usually carried some distance above the 500-volt direct-current trolley and feeders. An example of interurban overhead construction is shown in Fig. 29. Here the high-tension wires are carried on large porcelain insulators of a size necessary for 26,000 volts. These insulators are placed 36 inches apart. High-tension wires are kept so far apart because of the danger that arcs will in some way be started between the lines, as the high-tension current will maintain an extremely long arc. The blowing of green twigs across the lines, or birds of sufficient size flying into the lines, is likely to establish arcs which will temporarily short-circuit the line. The greater the distance apart of the wires, the less danger that such things will occur.

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[illegible] with a [illegible] the [illegible] of a table which gives the [illegible] according to the [illegible] the proper number and size of [illegible]. The most difficult thing to determine [illegible] be placed upon any section of the line [illegible] times when cars are bunched together [illegible] out of the question to provide enough feeder copper to keep the loss in voltage within reasonable limits at such times. The [illegible] any load upon any feeder is used as the basis of [illegible] cases. The amount of current required per car [illegible] weight of the car and the character of the service. This will be taken up later under the head of "Operation."

THIRD RAIL.

Location. The third-rail system of conducting current to electric cars, as most commonly employed in the United States, follows the example set by the Metropolitan West Side Elevated Railway of Chicago. All the elevated roads in the United States are now operated by means of third rails located at one side of the track. The third rail is an ordinary T rail and is located with the center of its head 20 inches outside of the gage line of the nearest track rail, and 6$\frac{3}{16}$ inches above the top of the track rail. On a few inter-urban roads this distance has been increased in order to accommodate certain steam railroad rolling stock which must at times be operated over the line.

Insulators. The third rail is supported every fifth tie on an insulator. These insulators on first construction were made of wooden blocks boiled in paraffine, but at the present time more substantial forms of insulation are being used.

One form of third-rail insulator, known as the "Gonzenbach," has a base of cast iron resting on the tie. Over this is placed a cap of insulating material similar to that used in strain and trolley-wire insulators. Over this insulating material is another cast-iron cap upon which the third rail rests. The weight of the third rail holds it in position, and there is no clamping together of the various parts of the insulator.

Another form of third-rail insulator is made of what is called "reconstructed granite," and another of vitrified clay. Fig. 31 shows one of the latter.

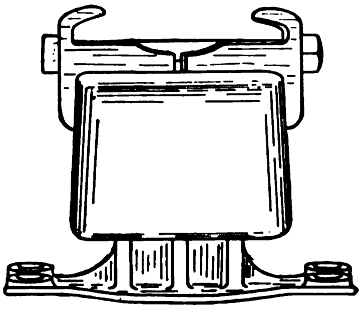


Fig. 31. Third-rail Insulator.

Switches. Where the third rail is used, a contact shoe is placed on each side of both trucks of the motor car. At switches it is necessary to omit the third rail for a short distance on one side of the track, and place a short section of third rail on the other side of the track so that the current supply to the car will be uninterrupted.

At Highway Crossings. Where the third-rail system is employed on interurban surface lines, it is necessary to omit a section of it at every highway crossing. If the crossing is too wide to be bridged across by a car, the car must have sufficient momentum to drift over such crossings when it comes to them. To connect across the break in the third rail at such points, an underground cable is generally used. This cable must be thoroughly protected against leakage of moisture into the insulation where it comes to the surface for connection to the third rail.

Another form of third rail, laid several years ago on some of the lines of the New York, New Haven & Hartford Railroad, was of an inverted V shape, and was laid midway between the track rails with its top 1 inch above them and its bottom only $1\frac{5}{8}$ inches above the ties. It was supported on wooden blocks. This location of the third rail has never been popular, because of the poor insulation with the rail located so close to the ties between the rails.

Conductivity. The conductivity of a steel rail varies considerably. A rail of the ordinary composition used on steam railroads is too high in carbon to give the best conductivity. Such a rail has about one-tenth the conductivity of the same cross-section of copper. Steel can easily be obtained, however, which will have one-seventh the conductivity of copper, and the additional cost of obtaining such special steel is quite low, so that the majority of roads installing the third-rail system have seen fit to pay the extra cost and thereby secure a softer rail than that usually employed in track rails.

Cost. The cost of the third-rail system is less than an overhead trolley system, provided enough copper is placed in the trolley feeders to make the conductivity of the trolley system equal to that of the third-rail system. It is very seldom, however, that a trolley system is so constructed on an inter-urban road; and hence the trolley system, as usually constructed, is cheaper than the third-rail system, because it is not of equal conductivity to a third-rail system.

Advantages in Operation. Where very heavy cars or trains are to be operated, the third-rail system is decidedly an advantage, for two reasons. In the first place, it affords the cheaper method of conducting a given heavy volume of current; and in the second place, the contact shoes that conduct the current from the third rail to the moving car or train are built to carry a much larger volume of current than the trolley wheel, which has only a small area of contact on the trolley wire. Ordinarily there are two of these contact shoes in multiple for every motor car.

Another advantage of the third rail over the trolley is that the trolley may leave the wire at high speeds or in passing switches. On well-constructed roads, where the trolley wire is kept in good alignment and the track is smooth, there is little trouble from this source; but it is undoubtedly a convenience to be able to operate cars or trains without giving any attention to a trolley pole.

CONDUIT SYSTEMS.

The underground conduit system, in which the conductors conveying the current to the cars are located in a conduit under the tracks, is in use in two cities of the United States—New York City and Washington, D. C. The cost of this system, and the danger of interruption of the service where the drainage is not excellent, have prevented its more extensive adoption.

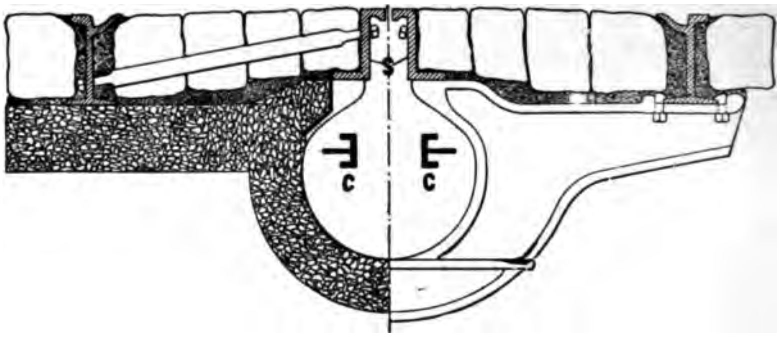


Fig. 32. Cross-section of Conduit.

The New York type of conduit is a good example of this construction. The conductors consist of T-bars (CC) of steel supported from porcelain cup insulators located 15 feet apart in the conduit. A cross-section of the conduit is shown in Fig. 32. At each insulator a hand-hole is provided (Fig. 33), so that access may be had to the insulator from the street surface. Manholes are provided at intervals of about 150 feet, so that the dirt which collects in the conduit can be scraped into these manholes and removed at intervals. The manholes also serve as points of drainage to the sewer system.

Contact Plow. Current is conducted to the car through a pair of contact shoes commonly called **a plow** (Fig. 34). This plow has the two shoes insulated from each other, and from the frame of the plow. They are provided with flat springs that hold the shoes against the conducting bars in the conduit. The shank of the plow is thin enough ($\frac{9}{16}$ inch) to enter the slot of the conduit. The conductors pass up through the middle. These plows can, of course, be removed only when the car is over an open pit.

Cost. A conduit system of this kind is very expensive to build because of the fact that a very deep excavation must be made in the street to accommodate the conduit. The track rails, slot rails, and sheet-steel conduit lining are held in alignment by cast-iron yokes placed 5 feet apart. The entire space around and underneath these yokes is filled with concrete in order to give rigidity and a permanent track. Three expensive items, therefore, enter into the construction of a conduit road—namely, the deep excavation, which may call for the changing of other underground pipes or conduits in the street; the large amount of iron and steel needed for the yokes and slot rails; and the large amount of concrete needed.

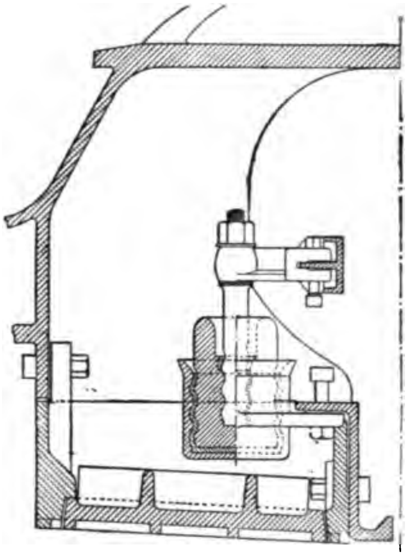


Fig. 33. Hand hole.

On American conduit roads the slot and conduit are placed under the middle of the track. Some of these roads are simply reconstructed cable-conduit roads in which the old cable conduit has been used for electrical conductors. In the conduit road Buda-Pest, Hungary, the slot is placed alongside one of the t rails.

Current Leakage. The leakage on an underground conduit road is considerable, because the insulators are necessarily located in a damp, dirty place, which causes leakage over the surface of the insulators. This leakage, however, is not prohibitive so long as the conductor rails are not under water. If on account of poor drainage the conductor rails become submerged, the leakage becomes so great that it is impossible to operate the road.

It will be noticed that the conduit system as illustrated here employs two conductor rails, one for the positive side of the circuit and the other for the negative. The track rails, therefore, are not used as conductors, and one side of the circuit is not grounded as in the ordinary trolley system, although the leakage to ground may be considerable from one or both conductor rails.

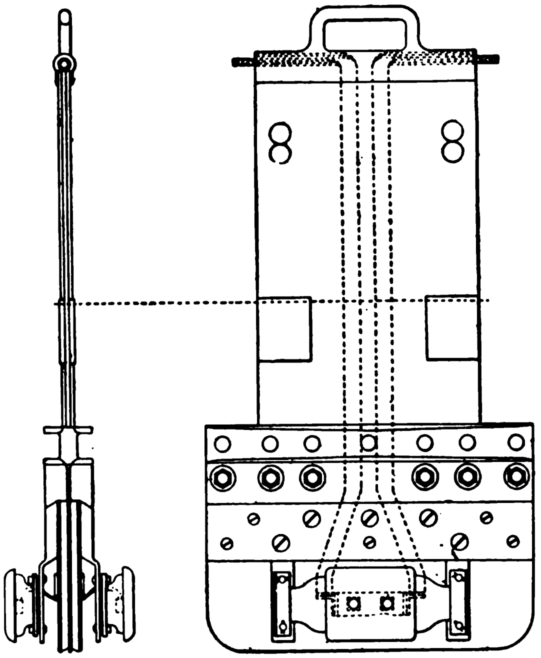


Fig. 34. Contact Plow.

TRACK CONSTRUCTION.

Girder Rail. A great variety of track rails are used in electric railways. The most common at one time was the girder, a typical section of which, with joint, is illustrated in Fig. 35. This is an outgrowth of the old tram rail used on horse railways. It has a tram alongside of the head, on which vehicles may be driven. Its chief advantage from the standpoint of the railway company is that there is plenty of room for dirt and snow to be pushed away by the flanges of the cars. If the company maintains the paving, it may be to its advantage to have teams use the steel track rather than the paving, although this advantage in maintenance is probably more than compensated for by the delay of cars through the regular use of the track by teams.

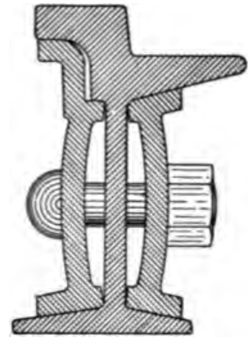
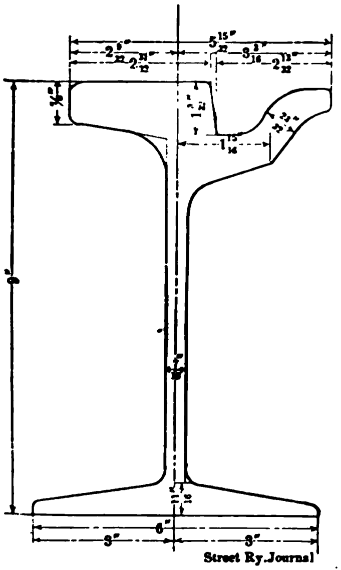


Fig. 35. Girder Rail.

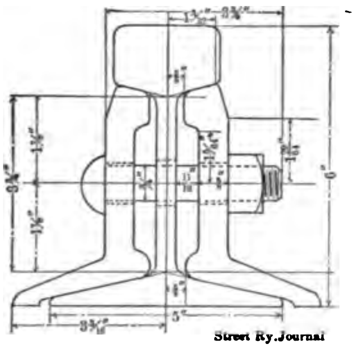
Trilby Groove Rail. A modification of the girder rail, known as the **Trilby,** and sometimes as the **grooved girder,** is shown in Fig. 36. A rail similar to this is used in several large cities of the United States. It has a groove of such a shape that the flanges of the car wheels will force snow and dirt out of it instead of packing it into the bottom of the groove, as in the case of the regular European narrow-grooved rail. A narrow-grooved rail in which the grooves correspond closely to the shape of the car-wheel flanges is sure to make trouble in localities where there is snow and ice, as the grooves become packed and derail the cars.

Shanghai T-rail. In some systems a T-rail is used. Where the T-rail is to be used with paving, the popular form is the Shanghai T, shown in Fig. 37. This rail is high enough to permit the use of high paving blocks around it.



Street Ry. Journal

Fig. 36. Grooved Rail.

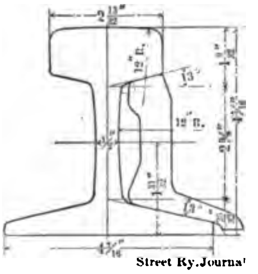


Street Ry. Journal

Fig. 37. Shanghai T-rail and Joint.

Common T-rail. The T-rail used by steam railroads is known as the A. S. C. E. standard T-rail, because it follows the standard dimensions recommended for T-rails by the American Society of Civil Engineers. A standard 65-pound T-rail of this kind is shown in Fig. 38. Other weights of this rail have the same relative proportions. Such a rail is used for inter-urban roads, and for suburban lines in streets where there is no block paving. The high rails are used to facilitate paving with high paving blocks.

Track Support. The greater portion of track is laid on wooden ties. These ties, in the most substantial wooden tie construction, are 6 inches by 8 inches in section, and 8 feet long. They are spaced two feet between centers. Sometimes smaller ties, spaced farther apart, are used in cheaper forms of construction; but the foregoing figures are those of the best construction known in American railway practice. In paved streets, ties are usually employed, although sometimes what is known as "concrete stringer" construction is used instead of ties to support the rails. A strip of concrete about 12 inches deep is laid under each rail, and the rails are held to gauge by ties or tie rods placed at frequent intervals. Sometimes the concrete is made a continuous bed under the entire track. In most large cities the concrete foundation is used under all paving; and consequently, when concrete is used instead of ties to support the rails, this concrete is simply a continuation of the paving foundation. Where ties are used, they are laid sometimes in gravel, crushed stone, or sand, although frequently, in the largest cities, they are embedded in concrete. Sometimes this concrete is extended under the ties, and sometimes it is simply put around the ties.



Street Ry. Journal

Fig. 38. Standard A. S. C. E. Rail and One Joint Plate.

Ballast. A ballast of gravel, broken stone, cinders, or other material which is self-draining and which will pack to form a solid bed under the ties, should be used to get the best results under all forms of tie construction, whether in paved streets or on a private right of way, as on an inter-urban road. Of course, if concrete is placed under the ties, the gravel or rock ballast is not necessary. If ties are placed directly in soft earth, which forms mud when wet, they will work up and down under the weight of passing trains, and an insecure foundation for the track will be the result.

Joints. The matter of securing a proper joint for fastening together the ends of rails so as to make a smooth riding track without appreciable jar or jolt when the wheels pass a joint, has been given much study by electric railway engineers. A section through an ordinary bolted angle-bar joint is shown in Fig. 35. This joint is formed by bolting a couple of bars, one on each side of the rails. The edges of these bars are made accurately to such an angle that they will wedge in between the head and base of the rail as the bolts are tightened; hence the name **angle bars**. This is the form of joint generally used on steam railroads and on electric roads in exposed track, or in track where the joints are easily accessible, as in dirt streets. In paved streets, the undesirability of tearing up the pavement frequently to tighten the bolts on such joints, has led to the invention of several other types, which will be described later. Nevertheless very good results have been obtained in recent years with bolted joints laid in paved streets where care has been given to details in laying the track, and where the joints have been tightened several times before the paving is finally laid around them.

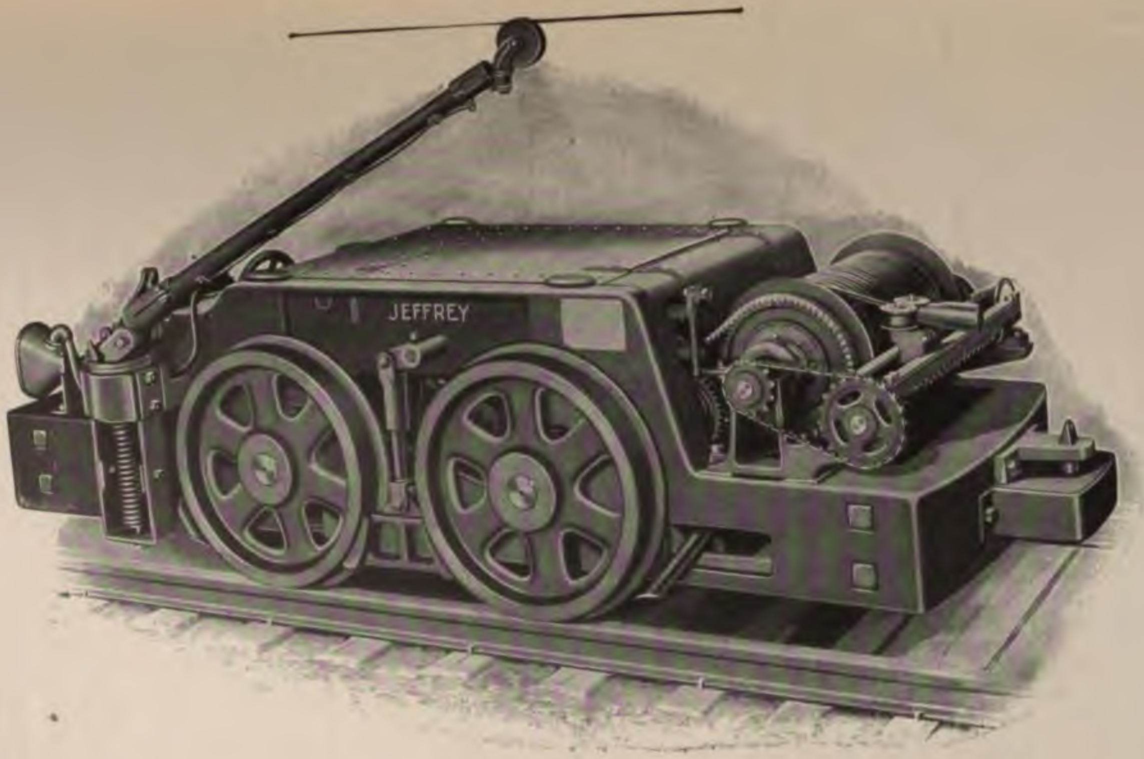
Welded Joints. Several forms of welded joints are in use. All these welded joints fasten the ends of the rails together so that the rail is practically continuous—just as if there were no joints—so far as the running surface of the rail is concerned. It was thought at one time that a continuous rail would be an impossibility because of the contraction and expansion of the rail under heat and cold, which, it was thought, would tend to pull the rails apart in cold weather and to cause them to bend and buckle out of line in hot weather. Experience has conclusively shown, however, that contraction and expansion are not to be feared when the track is laid in a street where it is covered with paving material or dirt. The paving tends to hold the track in line, and to protect it from extremes of heat and cold. The reason that contraction and expansion do not work havoc on track with welded joints, is probably that the rails have enough elasticity to provide for the contraction and expansion without breaking.

It is found that the best results are secured by w joints during cool weather, so that the effect of contraction in the coldest weather will be minimum. In this case, of course, there will be considerable expansion of the track in the hottest weather, but this does not cause serious bending of the rails; whereas occasionally, if the track is welded in very hot weather, the contraction in winter will cause the joint to break.

Cast-Welded Joints. The process of cast-welding joints consists in pouring very hot cast-iron into a mould placed around the ends of the rails. These moulds are of iron; and to prevent their sticking to the joint when it is cast, they are painted inside with a mixture of linseed oil and graphite. Iron is usually poured so hot that, before it cools, the base of the rail in the center of the molten joint becomes partially melted, thus causing a true union of the steel rail and cast-iron joint. This makes the joint solid mechanically and a good electrical conductor. To supply melted cast iron during the process of cast-welding joints on the street, a small portable cupola on wheels is employed.

Electrically Welded Joints. An electrically welded joint is made by welding steel blocks to the rail ends. A steel block is placed on each side of the rail at the joint, and current of very large volume is passed through from one block to the other. This current is so large that the electrical resistance between the rail and steel block causes that point to become molten. Current is then shut off, and the joint allowed to cool. There is in this case a true weld between the steel blocks and the rails and joint.

An electric welding outfit being expensive to maintain and operate, this process is used only where a large amount of welding can be done at once. Current is taken from the trolley wire. A rotary converter set takes 500-volt direct current from the trolley wire, and converts it into alternating current. This alternating current is taken to a static transformer which reduces the voltage and gives a current of great quantity at low voltage, the latter current being passed through the blocks and rails in the welding process. A massive pair of clamps is used to hold the blocks against the rails, and to conduct the current to and from the joint while it is being welded. These clamps are water-cooled by having water circulated through them so that they will not become overheated at the point of contact with the steel blocks.



JEFFREY 2½-TON ELECTRIC LOCOMOTIVE

With Outside Wheels.

THE NEW YORK
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ASTOR, LENOX
TILDEN FOUNDATIONS

Thermit Welding. A process of welding rail joints which was developed after the cast-welding and electric-welding processes, is known as the **Goldschmidt process,** which makes use of a material called "thermit" for supplying heat to make the weld. A mould is placed around the joint and the thermit is put in this mould and ignited. The heat produced by the thermit is so intense as to reduce the iron in the thermit mixture and make a welded joint. The thermit consists of a mixture of finely powdered aluminum and iron oxide. When this is ignited, the aluminum oxidizes, that is, absorbs oxygen so rapidly that an intense heat is the result. In the process of oxidation, the aluminum takes the oxygen from the oxide of iron, leaving molten metallic iron, which metallic iron makes the weld by union with the molten rail ends. This process has the advantage over other welding processes, of not requiring an elaborate apparatus and a large crew of men to operate it; and consequently it can be used where but a few joints are to be welded.

Bonding and Return Circuits. When the track rails are used as the conductors, as is usually the case, it is necessary to see that the electrical conductivity of the rail joints does not offer too high a resistance to the passage of the current. For this reason, when bolted or angle-bar joints are used, the rails are bonded together by means of copper bonds. It was soon found after electric roads were in use a short time, that unless the rail ends were so bonded the resistance of the joints was so great as to cause great loss of power in the track. First, small iron bonds were used; but these bonds were so insufficient that large copper-wire bonds soon began to be used; and at the present time, on large roads, bonds of heavy copper cable are common. The resistance of a steel rail, such as used in city streets, is about eleven times that of copper. In order to secure as great carrying capacity at the rail joint as is afforded by the unbroken rail, it is therefore necessary to install bonds having a total cross-section $\frac{1}{11}$ that of the rail. Where welded joints are used, bonding is unnecessary, except at crossings and switches where bolted joints are employed. Where track is welded, however, cross-bonds should be put in at frequent intervals from one rail to another, and, if th
double, from one track to the other, so that if one

breaks at a joint there will be a path around the break for the current.

A great many schemes have been devised to insure good contact between the copper bond and the rail, as the terminal is the weak point in any bond. One of the earliest and most efficient of small bonds was made by the use of channel pins, Fig. 39. This bond consisted of a piece of copper wire having its ends placed in the holes in the rail ends. Alongside this wire, a channel pin was driven in. The objection to the channel pin was the small area of contact between copper bond and rail.

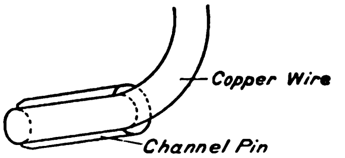

Fig. 39. Channel Pin Bond.

Next after the channel pin came the Chicago type of bond, Fig. 40, which is a piece of heavy copper wire with thimbles forged on the ends. These thimbles were placed in accurately fitted holes in the rail ends, and a wedge-shaped steel pin was driven into the thimbles to expand them tightly into the hole in the rail. Several other bonds using modifications of this principle are in use.

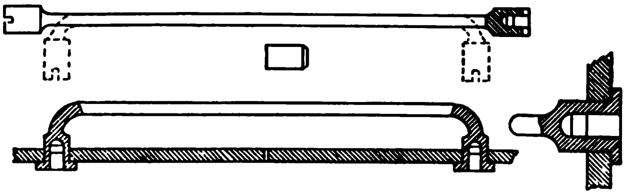

Fig. 40. Chicago Rail Bond.

A type of bond in very common use consists of solid copper rivet-shaped terminals, Fig. 41. Between these terminals is a piece of flexible stranded copper cable, made flat to go under the angle bars. In one type the terminal lugs are cast around the ends of the cables, and in another type the cables are forged at their ends into solid rivet-like terminals. These terminal rivets were first applied as any other rivets, with the use of a riveting hammer. Because of the difficulty of thoroughly expanding such

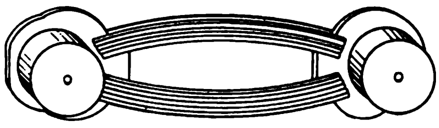

Fig. 41. Rail Bond.

large rivets into the holes made for them in the rails, it has become customary to compress these rivets either with a screw press or a portable hydraulic press, which brings such great pressure to bear on the opposite ends of the rivet that it is forced to expand itself so as to fill the hole in the rail completely. This expansion is made possible by the ductile character of the copper. This great ductility characteristic of copper, however, has been the source of one of the difficulties in connection with rail bonding, because the soft copper terminal has a tendency to work loose in the hole made for it in the rail. It is practically impossible to maintain good bonding where the rail joints are so loose as to allow considerable motion between the rail ends.

Several types of bonds have been introduced, in which the contact between the rail and bond is made by an extra piece or thimble.

Another method of expanding bond terminals into the holes made to receive them, is that employed in the General Electric Company's bond. In it a soft steel pin in the center of the terminal is expanded by compression of the terminal so that it forces the copper surrounding it outward. The copper terminal, in expanding to fill the hole, is therefore backed by the steel center pin.

All types of bonds must be installed with great care if they are to be efficient. Unless the bond terminal thoroughly fills the hole and is tightly expanded into it, moisture will creep into the space between the copper and the iron, and the copper will become coated with a non-conducting scale which destroys the conductivity of the contact.

The **plastic** rail bond, so called because it depends for the contact between the rail and the bond upon a plastic, putty-like alloy of mercury and some other metal, is applied in a number of different ways. One form consists of a strip of copper held by a spring against the rail ends under the fish-plate. The rail-ends at the point of contact with this strip of copper are amalgamated and made bright by the use of a mercury compound similar to the plastic alloy. These points of contact are then daubed with plastic alloy, and the copper bond-plate applied. It is not necessary, with any form of plastic bond, that the mechanical contact be unyielding, as the amalgamated surfaces with the aid of the plastic alloy between them. maintain a good conductivity in spite of any slight motion. The plastic alloy can be applied in a number of other ways, one of which is to drill a hole forming a small cup in the rail-base in adjacent rail-ends, fill these cups with plastic alloy, and bridge the space between them with a short copper bond having its ends projecting down into the cups.

Supplementary Return Feeders. On some large roads it is necessary to run additional return feeders from the power house to various points on the system, to supplement the conductivity of the rails. Otherwise the track rails near the power house would have to carry all the current, and in some cases there are not enough such lines of track passing the power house to do this properly. Sometimes these feeders are laid underground in troughs; sometimes they are laid bare in the ground, and sometimes on overhead pole lines. When laid in the ground, frequently old rails are used instead of copper or aluminum cables. The old rails are, of course, thoroughly bonded together with bonds giving a conductivity nearly equal to that of the unbroken rail.

ELECTROLYSIS.

Much has been said about the possibilities of electrolysis of underground metal by the action of the return current of electric railways, when such railways are operated with grounded circuits, as they usually are. If electric current is passed through a liquid from one metal electrode to another, electrolysis will take place; that is, metal will be deposited on the negative pole, and the positive pole or electrode will be dissolved by becoming oxidized from the action of the oxygen collecting at that pole.

In an electric-railway return circuit, there is necessarily a difference of potential between the rails at outlying parts of the system and the rails and other buried pieces of metal located near the power house. Just what this total difference of potential is, depends on the loss of voltage in the return circuit. Thus, suppose there is 25 volts drop in the return circuit between a certain point on the system and the power station. There is, therefore, a pressure of 25 volts tending to force the current through the moist earth from the rails at distant portions of the line, to the rails, water pipes, and other connected metallic structures located in the earth near the power station. The amount of current that will thus flow to earth in preference to remaining in the rails, depends on the relative resistance of the rails, the earth, and the other paths offered to the current to return to the power house.

To take a very simple case, let us suppose a single-track road, Fig. 42, with a power house at one end, and a parallel line of water pipe on the same street passing the power house. If the positive terminals of the generators are connected to the trolley wire, the current passes, as indicated by the arrows, out over the trolley wire through the cars and to the rails. When it has reached the rails it has the choice of two paths back to the power house. One is through the rails and bonding; the other is through the moist earth to the line of water pipe and back to the power house, leaving the pipe for the rails at the power house. Should the bonding of the rails be very defective, considerable current might pass through the earth to the water pipe.

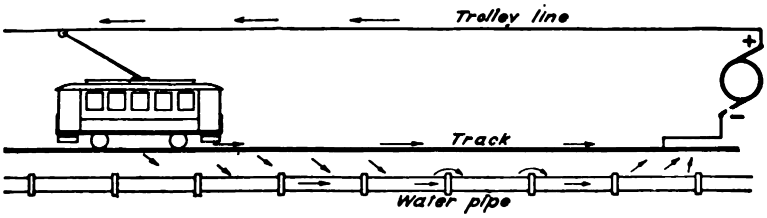

Fig. 42. Showing Electrolytic Action.

Remembering now the principles of electrolysis, we see that the oxidizing action of this flow of current from the rails to the water pipes at the distant portion of the road will tend to destroy the rails, but will not harm the water pipe at that point, as it will tend to deposit metal upon it. When, however, the current arrives at the power house, it must in some way leave this water pipe to get back to the rails, and so to the negative terminals of the generators.

Here we see that there is a chance for electrolysis of the water pipe, because at this point the water pipe forms the positive electrode, which is the one likely to be oxidized and destroyed. This very simple case is taken merely for illustration. In actual practice the conditions are never so simple as this, for there are various pipes located in the ground running in various directions, which complicate the case very much; but we can see from this simple example that the principal place electrolysis of water pipe is to be feared is at points where a large volume of current is leaving the water pipe to take to some other conductor.

As an indication of how much current is likely to be leaving the water pipes at various points, it is customary to measure the voltage between the water pipes and the electric railway track and rails. When this voltage is high, it does not necessarily mean that a large volume of current is leaving the water pipes at the point where these pipes are several volts positive with reference to the rails; but such voltage readings indicate that, if there is a path of sufficiently low resistance through the earth, and if the moisture in the earth is sufficiently impregnated with salts or acids, there will be trouble from an electrolytic action due to a large flow of current. There is obviously no method of measuring exactly the amount of current leaving a water pipe at any given point, since the pipe is buried in the earth. Voltmeter readings between pipes and rails simply serve to give an indication as to where there is likely to be trouble from electrolysis. The danger to underground pipes and other metallic structures from electrolysis has been much overestimated by some people, as the trouble can be overcome by proper care and attention to the return circuit. Trouble from electrolysis, however, is sure to occur unless such care is given.

Prevention of Electrolysis. Remedies for electrolysis may be classified under two heads—general and specific. The general remedy is obviously to make the resistance of the circuit through the rails and supplementary return feeders so low that there will be but little tendency for the current to seek other conductors, such as water and gas pipes and the lead covering of underground cables. This remedy consists in heavy bonding, in ample connections, around switches and special work where the bonding is especially liable to injury, and in additional return conductors at points near the power house to supplement the conductivity of the rails.

It is important that all rail bonds be tested at intervals of six months to one year in order that defective bonds may be located and renewed, as a few defective bonds can greatly lower the efficiency of an otherwise low-resistance circuit.

The specific remedy for electrolysis which may be applied to reduce electrolytic action at certain specific points, consists in connecting the water pipe at the point where electrolysis is taking place, with the rail or other conductor to which the current is flowing. Thus, for example, if it is found that a large amount of current is leaving a water pipe and flowing to the rails or to the negative return feeders at the power house, the electrolytic action at this point can obviously be stopped by connecting the water pipe with the rails by means of a low-resistance copper wire or cable, thereby short-circuiting the points between which electrolytic action is taking place. There are certain cases in which it is advisable to adopt such a specific remedy. It should be remembered, however, that a low-resistance connection of this kind, while it reduces electrolysis at points near the power house, is an added inducement to the current to take to the water pipes at points distant from the power house, because of the decrease in resistance of the water-pipe path back to the power house resulting from the introduction of the connection between the water pipe and the negative return feeder at the power house. With the water pipes connected to the return feeders in the vicinity of the power house, the current which flows from the rails to the water pipes at points distant from the power house will obviously cause electrolysis of the rails but not of the water pipes, since the current is passing from the earth to the pipe, and the pipe is negative to the earth. In this case the principal danger is that the high resistance of the joints between the lengths of water pipe will cause current to flow through the earth around each joint, as indicated on some of the joints, Fig. 42, and will cause electrolytic action at each joint. It is evident, however, that the conditions of the track circuit and bonding must be very bad if current would flow over a line of water pipe, with its high-resistance joints, in sufficient volume to cause electrolysis, in preference to the rail-return circuit, especially since ordinarily the resistance offered to the flow of current over the water pipes back to the power house must include the resistance of the earth between the tracks and water pipes.

It is usually considered inadvisable to connect tracks and water pipes at points distant from the power house, because of the danger of electrolysis, at water-pipe joints, as just explained.

Methods of testing rail bonds in the track will be explained under the head of "Tests."

POWER SUPPLY AND DISTRIBUTION.

Direct-Current Feeding. As already explained, the majority of electric railways are operated on a 500-volt constant-potential direct-current system with a ground return. A constant potential of 450 to 500 volts is maintained between the trolley wire and track. Where the trolley wire is not sufficient, additional feeders are run from the power house and connected to the trolley wire, the number of feeders depending on the distance from the power house and the traffic.

Booster Feeding. Boosters are sometimes used on long feeder lines where there is a heavy load only a small portion of the time. These boosters are direct-current dynamos that are connected in series with the feeder upon which the voltage is to be raised above the regular power-house voltage. The booster may be driven either by a small steam engine or by an electric motor. The simplest form of booster is a series-wound dynamo. A booster armature must, of course, be of sufficient current capacity to pass all the current that will be required on its feeder. The voltage yielded by this dynamo, plus the power-station voltage, is the voltage of the boosted feeder as it leaves the power house. Supposing that a series-wound booster will give 125 volts at full load; it is obvious that being series-wound it will give no voltage at no load. The voltage will increase approximately as the load on the feeder increases; and since the drop in voltage on the feeder for which the booster is to compensate also varies with the load, the action of the booster is simply to add sufficient voltage to its feeder at any instant to compensate for the line loss upon that feeder and to maintain approximately constant potential at the far end of the feeder. Boosters raising the power-station voltage of a feeder more than 250 volts above the normal power-station voltage, are not common, though cases are on record where a feeder has been boosted as high as 1,100 volts above the power-station voltage. Since all the power used in driving a booster is wasted in line loss, this method of feeding is not economical; but where used only a few days out of the year it is sometimes to be preferred to a heavy investment in feeders. The investment in feeders might involve more interest charges than the cost of power wasted in booster feeding would amount to.

Alternating-Current Transmission. High-tension alternating-current transmission to sub-stations, with direct-current distribution from sub-stations, is extensively used on long inter-urban roads, and on large city street-railway systems where power is to be distributed over a wide area. In such cases the power house is equipped with alternating-current dynamos supplying high-tension three-phase alternating current to high-tension transmission lines or feeders. These high-tension feeders are taken to sub-stations located at various points on the road where the voltage is reduced by step-down transformers; and these transformers supply current to operate rotary converters, which convert from alternating to direct current for use on the trolley.

The advantage of this system of high-tension distribution is that, owing to the high transmission voltage, there is but a small loss in the high-tension lines, which lines can be made very small, and will thus involve but little copper investment. The sub-stations can be located at frequent intervals, so that the distance the 500-volt direct-current must be conducted to supply the cars is not great. Current from one power-house can thus be distributed over a very large system in cases where, if the 500-volt direct-current system of distribution were used, the cost of feeders for distributing such a low-voltage current would be prohibitive. Were the alternating-current high-tension scheme of distribution not used, it would be necessary to have a number of small power houses at various points on the system instead of one large power house. The cost of operation of several small power plants per kilowatt output, is likely to be much greater than that of one large power plant. The first cost of the alternating-current distributing system, including power house and sub-stations, is likely to be considerably higher than would be the cost of a number of small power houses; but in cases where alternating-current distribu
has been installed, it has been figured that the cost of oper

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] The uncertainty of the coal supply [illegible] another argument against placing the station where dependence must be placed upon wagons or inadequate railroad facilities.

Coal handling, after the coal has reached the station, is done by hand in the smaller power stations; but in larger power stations it has come to be the general practice to do as much of the handling as possible by means of automatic coal conveyors. The most elaborate power stations have means for dumping coal from cars into hoppers, from which it is conveyed by an endless chain provided with buckets, called **a coal conveyor,** to storage bins. Coal conveyors also take the coal from the storage bins, and deposit it in the hoppers of mechanical stokers in front of the boilers. Ashes are conveyed from under the boilers by the same kind of conveyors, and are dumped into hoppers, whence they are drawn into cars or wagons to be hauled away.

The coal, having been deposited in hoppers at the boiler front, is automatically fed into the furnaces by automatic stokers. One type of automatic stoker in common use is of the chain-grate or link-belt type, which is constructed like an endless sprocket chain, with links composed of heavy cast-iron blocks that serve as grate bars. This link belt or chain is kept in constant, slow motion by a small stoker engine or motor which operates all the stokers of a line of boilers. The coal is fed from the hopper onto the chain grate, and the chain is slowly moved under the boilers. As the coal on that part of the grate under the boilers is on fire, the fresh coal as it enters the furnaces is soon ignited. The grate is run at such a rate, and the thickness of the coal is so adjusted, that the coal is burned to an ash by the time it has traveled to the back of the furnace. There the grate turns down over a sprocket wheel, and the ashes are dumped into the ash pit as the grate revolves.

The boilers in most common use in large American electric-railway power houses are of the water-tube type, in which water is contained inside of a bank of tubes, the ends of these tubes being connected to drums or headers. The horizontal-return-tubular type of boiler is used in many of the smaller power stations, and vertical boilers are also in use.

The engines in the larger and more economical stations are generally of the Corliss compound-condensing type, running at speeds of from 60 to 120 revolutions per minute, according to the size of the unit. The smaller the unit, the higher the speed. In the smaller and older stations, simple Corliss engines belted to generators are frequently found, and high-speed engines also are used. It is the almost universal custom now, to place the generator directly on the engine shaft, making a direct-connected unit.

Steam turbines, in which the steam acts in jets against the blades of a turbine wheel, are beginning to come into use at the present time. These turbines rotate at very high speed, the largest and slowest speed-units running 600 r.p.m., and others at higher rates. As the output of any generator varies directly according to its speed, a very much smaller generator can be used when coupled to a high-speed steam turbine, to obtain a given output, than if the generator must be coupled to a Corliss steam engine which revolves at very low speed. The economy of the steam turbine at full load is about that of a compound-condensing Corliss engine, but is better on light loads than the engine. The turbine requires less building space and a much less expensive foundation.

Railway generators or dynamos for direct current are usually built with compound-wound fields, so that, as the load increases, they will automatically raise the voltage at their terminals to compensate for the drop in the feeders and to maintain a constant potential at the cars. Thus, if the line loss on a system is 10 per cent, or 50 volts at full load, the generators will be provided with shunt fields of sufficient strength to give 500 volts at no load, and with series field-coils which will add to the field strength enough to give 550 volts at full load. The amount of "compounding" —which is the term applied to this method of increasing voltage —may be any amount within reasonable limits. The pressure maintained at different companies' electric-railway power houses varies, but is usually between 500 and 600 volts.

Alternating-Current Generators. Alternating-current generators used for generating alternating current to be distributed at high tension, are generally constructed to give a three-phase current at 25 cycles per second. The voltage of these alternating-current generators is sometimes the voltage at which the power is to be transmitted, if the distances are not too great. A number of stations have alternating-current generators giving 6,600 volts at their terminals, which is a voltage well adapted to high-tension distribution within the limits of a large city. However, generators giving 11,000 volts at their terminals are now becoming common. For higher voltages than this, it is considered necessary to use step-up transformers, in order to raise the voltage to the proper pressure for transmission over long distances. In such cases there is no object in having a high generator voltage. At such stations the voltage of the generators adopted may be anything desired, and it varies according to the ideas of the constructing engineer. Voltages of 400, 1,000, and 2,300 are among those in most common use.

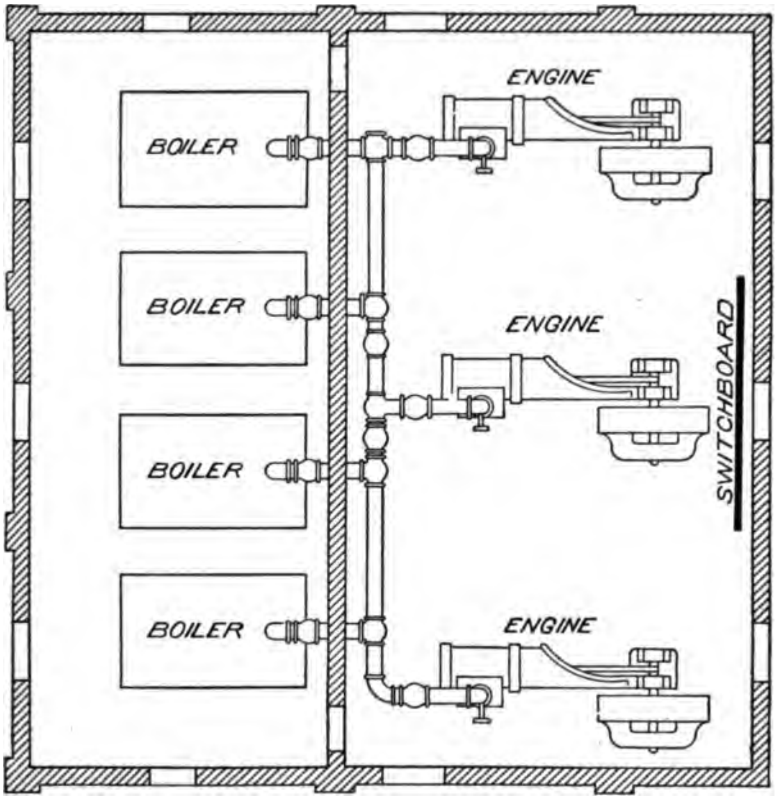

Fig. 43. Plan of Power House.

Double-Current Generators. Double-current generators are sometimes used, which generators will give direct current at a commutator at one end of the armature for use on a 500-volt direct-current distribution system supplying the trolley direct. The other end of the armature has collector rings from which the three-phase alternating current is obtained, which can be taken to step-up transformers and raised to a sufficient pressure for high-tension transmission to sub-stations at distant parts of the road. The same generator can therefore be used on both the direct-current and the high-tension alternating-current distribution.

General Plan of Power Stations. The general plan of an electric-railway power station is usually such that the building can be extended and more boilers, engines and generators added without disturbing the symmetrical design of the station. Thus, the boilers and engines are placed as in Fig. 43, in parallel rows, although almost invariably in different rooms separated by a fire wall. By adding to the row of engines and to the row of boilers, the station capacity can be increased. Other arrangements are sometimes required by circumstances; but this is the most common arrangement and gives the greatest capacity with the minimum amount of steam piping. Large stations are sometimes constructed with a boiler room of several floors and with boilers on each floor, in order to save ground space and bring the boilers near to the large engine units so that there will not be an excessive amount of steam piping.

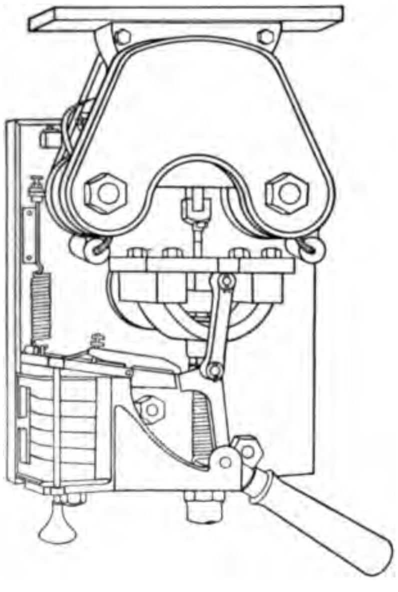
Fig. 44a. G. E. Circuit Breaker.

Switchboards. Direct-current stations have switchboards, which may be considered under two general classes—**generator boards** and **feeder boards.** Each board consists of panels.

Generator D. C. Panels. The generator panel usually contains an automatic circuit-breaker which will open the main circuit to the generator in case of an overload due to a short circuit. These circuit-breakers consist of a coil in the main circuit, which acts upon a solenoid. When the current in the coil exceeds a certain amount, the solenoid is drawn in, and a trigger is tripped which allows the circuit-breaker to fly open under the pressure of a spring. In one General Electric circuit-breaker, the main contact is made by heavy copper jaws, but the last breaking of the contact is made between points which are under the influence of a magnetic field. This magnetic field blows out the heavy arc that would otherwise be established. On the I-T-E, the Westinghouse and most other types of circuit-breaker, the breaking of the contact takes place between carbon points, which are not so readily destroyed by an arc as are copper contacts, and which are more cheaply renewed. The main contact through the circuit-breaker, in either type, is made between copper jaws of sufficient cross-section for carrying the current without heating. These jaws open before the current is finally broken by the smaller contacts which take the final arc.

In Fig. 44*a* is seen a General Electric circuit-breaker with the magnetic blow-out coils at the top, the solenoid at the left, and the handle for resetting the circuit-breaker at the bottom. The small handle for tripping the circuit-breaker when it is desired to open the circuit by hand, is shown just under the solenoid.

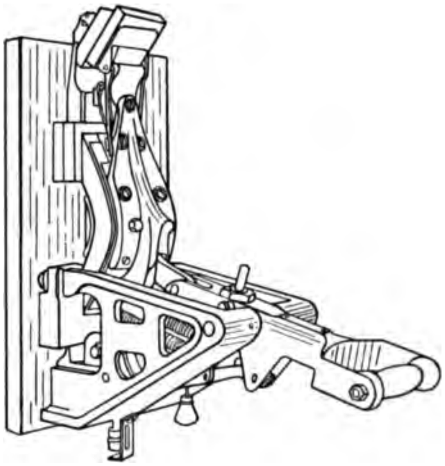

Fig. 44*b*. I-T-E Circuit Breaker.

An I-T-E circuit breaker is shown in Fig. 44*b*. This is of the type previously mentioned, in which the break occurs between carbon contacts and there is no magnetic blow-out.

In addition to the circuit-breaker there is usually an ammeter, to indicate the current passing from the generator; and a rheostat handle, geared to a rheostat back of the board, for cutting in and out more or less resistance in the shunt field-coils of the generator so as to reduce or raise the voltage. There is a small switch for opening and closing the circuit through the shunt field-coils.

The main leads from the generator pass through two single-pole quick-break knife switches. The most recent practice is to have the switches on the switchboard in only the positive and negative leads from the generator, leaving connection to the equalizer to be made by a switch located on or near the generator. However, all three leads may be taken to the switchboard, and a three-pole knife switch may be used instead of the positive and negative switches spoken of.

In Fig. 45 is given a simple diagram of the general relative connection of generators and feeders in a direct-current railway power station. It is seen that the generators are connected in parallel across the positive and negative bus-bar. There is a third bus-bar—called an "equalizing bus"—which connects in parallel the series coils of all the generator fields. The object of this equalizer is to prevent the weakening of the series field of any one generator, so as to allow it to take current and to act as a motor instead of as a generator.

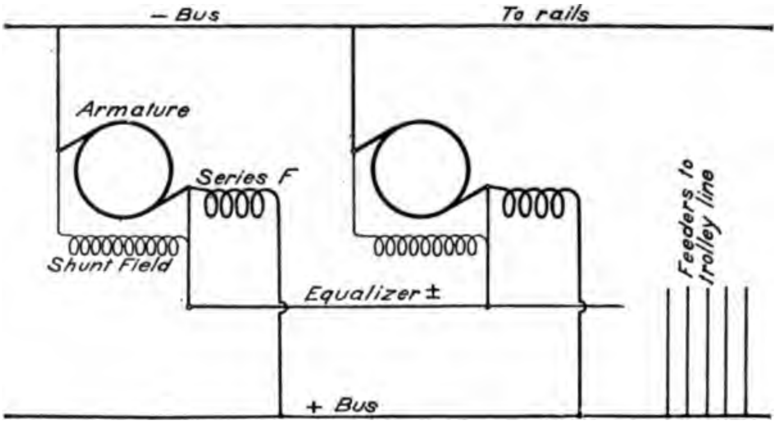

Fig. 45. Connection of Generators and Feeders.

Starting up a Generator. Suppose that a new generator is to be started up and connected to the bus-bars in addition to others already in operation. The engine of that generator is first brought up to speed. The switch controlling the shunt field-circuit is then closed, causing current to flow through the shunt fields; and the generator begins to "build up," its voltage gradually rising until

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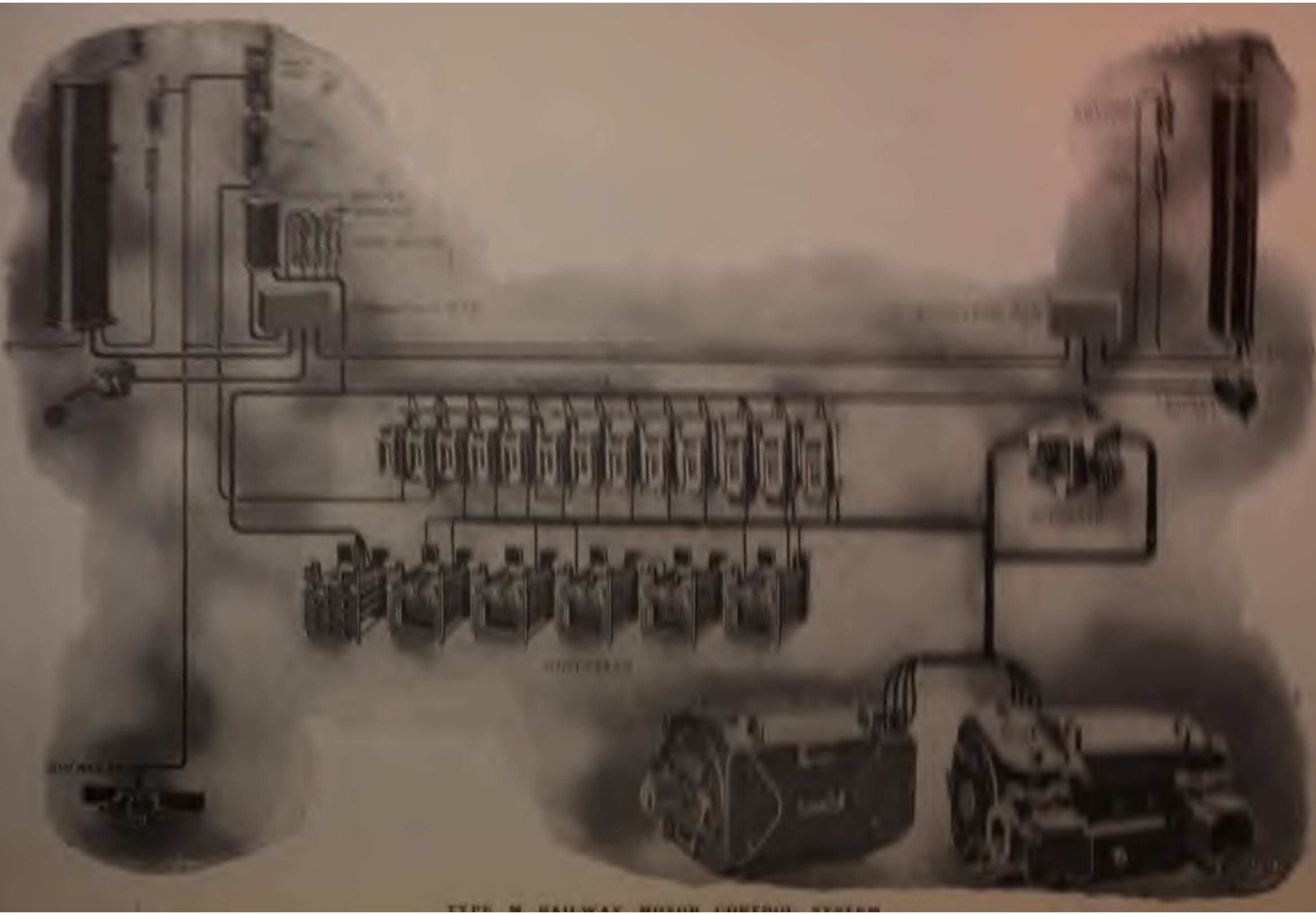

TYPE M RAILWAY MOTOR CONTROL SYSTEM

it approximates that upon the bus-bars. Before the generator is thrown in parallel with the others by connecting it with the bus-bars, it is important that its voltage be nearly the same as that of the bus-bars. Otherwise, when connected to the bus-bars, it might take more than its share of the load; while, on the other hand, if its voltage were too low, it might act as a motor, taking current from the bus-bars. The voltage of the bus-bars in a railway station is constantly fluctuating, owing to the varying load and to the fact that generators are often compounded, as before mentioned, in order to compensate for the line loss.

In order that the voltage of the generator to be thrown in shall vary in accordance with the bus-bar voltage, the next step in the operation is to close the positive switch, assuming that the equalizer switch on the generator has already been closed. This throws the series field of the new generator in parallel with the series fields of the other generators. The voltage of the new generator will therefore vary just as the voltage on the bus-bars; and, by adjusting the resistance of the shunt field, this voltage can be adjusted so as to be the same as that on the bus-bars. The voltages on the bus-bars and on the new generator are measured usually by a large voltmeter on a bracket at the end of the generator switchboard. By means of a voltmeter plug or of a push-button on the generator panel, the voltmeter can be connected either to the bus-bars or to the new generator. When the two voltages are the same, the negative switch of the new generator can be closed, and it will operate in parallel with the other generators, taking its share of the load. If the attendant sees that any generator is not taking its share, he can raise its voltage by cutting out some of the resistance in series with its shunt field, and this makes that generator take more load.

Feeder Panel. The feeder panel is simpler than the generator panel, since it usually handles only the positive side of the circuit. Frequently two feeders are run on a single panel side by side. The feeder panel has an automatic circuit-breaker, an ammeter for indicating the current on that feeder, and a single-pole switch for connecting the feeder to the bus-bars. All generators feed into a common set of bus-bars; and the positive bus-bar continues back of the feeder panels so that all feeders can draw current from the bus-bars. Fig. 46 shows a railway switchboard with 7 feeder panels at the right; 4 generator panels at the left; and, in the middle, a panel with an ammeter and recording wattmeter for measuring total output.

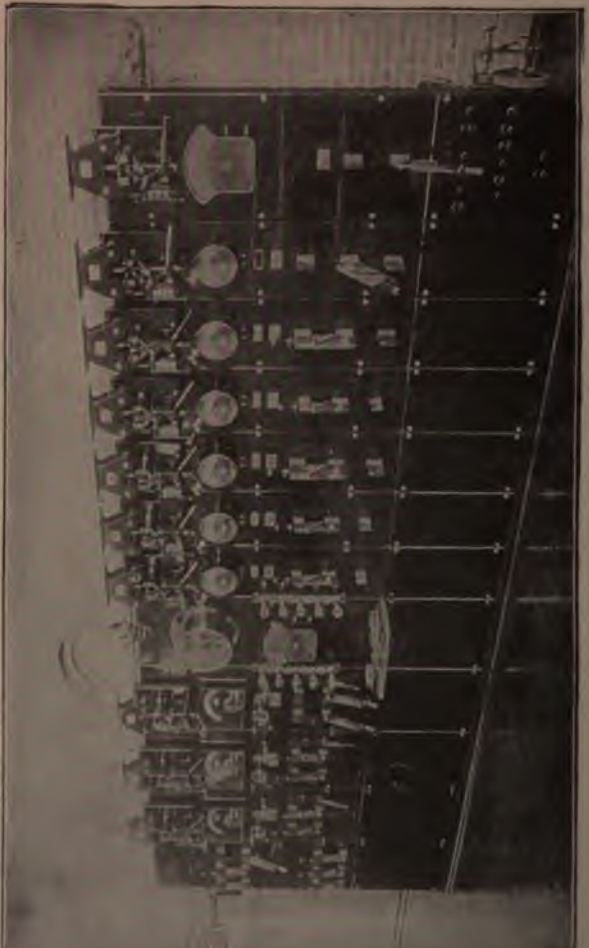

Fig. 46. Railway Switchboard.

In some stations two and even three sets of bus-bars are used, as it may be desired to operate different parts of the system at different voltages or to feed a higher voltage to the longer lines than to those near the station. In such a case double-throw switches are provided for connecting feeders and generators to either set of bus-bars.

Alternating-Current Switchboards. In an alternating-current station, generator switchboards are radically different from those in a direct-current station. Practice in alternating-current generator switchboards has not yet been so fully standardized and is not so uniform as in direct-current railway switchboards. There is always, however, a three-pole main switch for opening and closing the main three wires from the three-phase generator. Automatic circuit-breakers are usually provided, as well as indicating ammeters and wattmeters to show the output.

Indicating wattmeters, recording the number of watt-hours passing through them, are frequently used both on alternating and direct-current generator panels.

A station usually has what is called a "total load" panel, which has a recording wattmeter measuring the total output of the station in kilowatt-hours. This panel also has an ammeter indicating the total station load.

High-Tension Oil Switches. Alternating-current generators for high voltages usually have oil switches to interrupt the main circuit, that is, switches in which the contact is made and broken under oil. These switches have been found very efficient in preventing the formation of a destructive arc upon the opening of a high-voltage circuit, on circuits up to 60,000 volts. Some of the larger oil switches are operated by electric motors or solenoids. The machine-type oil switch of the General Electric Company has the motive power for operating the switches, stored up in a spring. The spring is wound up by a small electric motor. This motor operates every time the switch is opened or closed, and winds up the spring enough to compensate for the amount it was unwound in operating the switch. Each circuit is broken under oil in a long tube, and these tubes are mounted in individual cells, each cell being separated from the next by a masonry wall so that there can be no flashing across from one leg of the circuit to another in case of any defect in the switch. All the high-tension wiring to and from such switches, is taken either in lead-covered cables, or on bus-bars separated from each other by masonry walls to prevent the spread of short circuits. These precautions are necessary because of the great length of arc that may be established between adjacent high-tension conductors.

Where alternating-current generators of low voltage are used in connection with step-up transformers, one practice is to have the switches for each generator directly in the generator leads, between the generators and the step-up transformers, in the low-voltage circuit.

Another practice which has recently been introduced, is to consider each generator with its step-up transformers as a unit and to connect the generator permanently with its bank of transformers, and to control this unit by a single three-pole machine-operated oil switch. In this case there are no switchboard switches between generators and transformers, and this simplifies the switchboard considerably. There must be switches on the high-tension side of the transformers in any event.

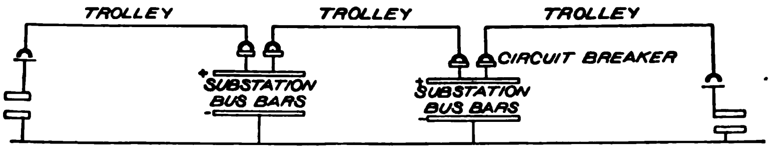

Fig. 47. Connection of Sub-stations.

The switchboard for rotary converters in the sub-stations is, of course, a combination of alternating and direct-current apparatus. The direct-current ends of the rotary converters are treated almost exactly like direct-current railway generators; and their switchboard panels are similarly equipped, except that usually there is a rheostat that can be connected in series with the armature whereby a rotary converter can be brought up to speed from a state of rest by connecting it with the direct-current bus-bars of the sub-station.

The alternating-current end of the rotary converter is supplied through switches in the alternating-current leads from the step-down transformers. A rotary converter can be started from a state of rest by connecting it to the alternating-current leads through the medium of compensating coils which reduce the voltage. A very heavy current is required to do this, as the motor thus starts as a very inefficient induction motor with a very low power factor.

There are usually but two direct-current feeder panels in a sub-station of an inter-urban electric road. One of these feeders is to supply the trolley or third rail extending in one direction from the sub-station, and the other feeds that extending in the other direction from the sub-station. The trolley or third rail has a section insulator directly at the sub-station. When both feeders are connected to the bus-bars, it is evident that this section insulator is short-circuited through the medium of the sub-station bus-bars, every sub-station on the line being connected in this way, as indicated in Fig. 47. It is seen that, should a short circuit occur on any section, it would open the circuit-breakers at the sub-stations at both ends, and that section would not interfere with the balance of the road. At the same time, when the road is in normal operation and there is an unusually heavy load between any two sub-stations, the other sub-stations along the line can help out those nearest to the load by feeding through the bus-bars of the nearest sub-station.

The high-tension apparatus at a sub-station consists usually of a bank of high-tension lightning arresters; high-tension switches, for shutting off the high-tension current; and step-down transformers, for reducing from the high transmission voltage to the 370 volts commonly fed to the alternating-current end of railway rotary converters.

Storage Batteries in Stations. Storage batteries are frequently used both in sub-stations and in direct-current power stations. They may be connected directly across the line and allowed to "float," as it is termed; or they may be used in connection with storage-battery boosters, which will cause the storage battery to take the fluctuations in the load and to give a constant load on the rotary converters or power station. The action of storage-battery boosters which cause the storage battery to be charged automatically at light loads and to discharge and assist the station at heavy loads, is explained in the paper on "Storage Batteries."

ALTERNATING-CURRENT SYSTEMS.

So far this paper has been devoted almost entirely to electric railway systems employing 500-volt direct-c [illegible] tors on the cars, since this is the system almost univers [illegible] electric railways at the present time. There are, however, several systems employing alternating-current motors on cars, which have already been used experimentally and to some extent commercially. Some of these give promise of coming into extensive use.

Three-Phase Motors. On several roads in Europe three-phase induction motors are employed. These induction motors are operated by three-phase alternating current taken direct from the trolley wires. As three conductors are necessary, two trolley wires are used, with the rails as the third conductor. The two principal objections to the system are the necessity of two trolley wires, and the fact that the induction motor operates very much like a direct-current shunt motor in that it is a constant-speed motor and not adapted to variable-speed work. The power factor is low in starting; that is, a great volume of current is taken, although, owing to the voltage and the current not being in phase, the actual energy consumed is small.

Single-Phase Motors. The Westinghouse Electric & Manufacturing Company has brought out a railway motor adapted to operate on single-phase alternating-current circuits. This motor is very similar in construction to the ordinary series-wound 500-volt direct-current railway motor. It has, however, more field poles than the ordinary direct-current motor; and the pole pieces are laminated to avoid heating of the iron by eddy currents caused by the influence of the alternating current. There are also other special features in the design that reduce the sparking at the commutator, which sparking was for several years the greatest obstacle to the use of alternating-current motors of this kind. In the Westinghouse system the current is taken from the trolley wire at high potential, and is reduced by an auto-transformer on the car. This auto-transformer is connected with an induction regulator so arranged that a low voltage can be supplied to the motor in starting or for slow running, and this voltage increased to increase the speed. There is thus no need to reduce the trolley voltage by wasting part of it in a rheostat, as is the case with direct-current motors; and the efficiency during acceleration is, therefore, higher with this alternating system than with the direct-current. Several other single-phase railway motors are also being worked out at the present time.

Alternating-Current Motor Advantages. There are two great advantages secured by the use of an alternating-current railway motor. The first is a reduction in investment and operating expenses by doing away with sub-stations containing rotary converters. Such sub-stations are necessary on long lines of railway operating with direct-current motors. The second advantage is that, owing to the fact that a high-tension current can be used on the trolley wire and reduced by a transformer on the car, the difficulties of collecting a large amount of energy from a trolley wire are much reduced.

First, in regard to the sub-stations, it will be seen that with the alternating-current motor system, high-tension current can be conducted from the power house to sub-stations along the line which contain nothing but static transformers. Since these transformers have no revolving parts they do not require the constant attendance that a rotary converter does. Furthermore, the investment in rotary converters is entirely dispensed with, and this makes a considerable reduction in the total cost of the distribution plant. With the alternating-current system, current is fed direct to the trolley wire from the secondary terminals of the transformers at the sub-stations.

As regards the advantages of carrying a high voltage on the trolley wire, it will readily be seen that, since the amount of power, or the watts required by a car, is equal to the product of the voltage and current, an increase in the voltage reduces the volume of current necessary. By having high voltage on the trolley wire, even a large car. can be operated with a small volume of current, and this current can be taken through an ordinary trolley wheel without difficulty. Where 500 volts is the pressure used on the trolley wire, there is considerable flashing and burning of trolley wheel and wire when large cars and locomotives are run, owing to the heavy current conducted; and this has been one of the principal reasons for the adoption of the third rail instead of the trolley on certain roads. Even with the third rail, the volume of current that must be conducted to large electric locomotives involves some difficulties in the way of heated contact shoes and considerable loss of energy. The use of high voltage on the trolley wire, with transformers on the car to reduce the voltage to a safe pressure for use on the motors, overcomes many of the difficulties that would otherwise be found in the use of electricity for heavy railroad work.

OPERATION.

Power Taken by Cars. The amount of power required in the practical operation of a car depends upon so many variable elements that many of the calculations sometimes given for determining the power required by a car are of little value. The theoretical horse-power required to maintain a car at a certain speed on a level, is evidently the tractive effort in pounds multiplied by the speed in feet per minute and divided by 33,000. What the tractive effort per ton of car will be, depends on the condition of the rail and on several other uncertain factors. For street-railway motor cars, 20 pounds per ton is the usual tractive effort assumed as necessary. A calculation of this kind, however, takes no account of the losses in the motors and gears, nor of the fact that the greater part of the power required to propel a street car in practical service is used in accelerating the car from a state of rest to full speed. In inter-urban service, of course, the power required in acceleration is not so great a proportion of the whole.

The safest figures to use in engineering calculations as to the amount of power required, are those taken from actual results obtained in every-day commercial service. The power required by an eight-ton car in service in a large city like Chicago, is in the neighborhood of one kilowatt-hour per car-mile run. On outlying lines this figure may be reduced to .7 kilowatt-hour, and in the down-town districts may run up to 1.5 kilowatt-hours per car mile. Double-truck cars in city service, weighing from 20 to 25 tons, take from 2½ to 4 kilowatt-hours per car mile at the power station. Inter-urban cars around Detroit, weighing about 32 tons, in inter-urban service, making 25 miles per hour, including stops, in level country, and geared to 43 miles per hour, take about 3 kilowatt-hours per car mile at the power station. However, inter-urban railway conditions are extremely variable.

Economy in Power. As already stated, a large part of the energy taken by a car in city service is used in accelerating the car. Much of this energy must be destroyed or used up in the brake shoes at the next stop. The energy stored up in a car by process of acceleration is represented by the formula:

$$\text{Energy in ft. lbs.} = \frac{\text{Mass in lbs.} \times (\text{Velocity in ft. per sec.})^2}{2},$$

which is the formula for kinetic or live energy, the derivation of which is found in the Instruction Paper on Mechanics. In performing any given schedule with frequent stops, the more rapid the acceleration the lower the maximum speed required to make the schedule, and the less the energy required in acceleration. For city street and elevated service, therefore, rapid acceleration and low maximum speeds are desirable because not only more economical but safer.

For economical operation with any given equipment and schedule, it is important to use as much of the energy stored up in the car as possible, before wasting it by applying the brakes. Motors are built of a size to yield the large horse-power required in acceleration, and consequently are lightly loaded when operating the car at maximum speed. To economize in power, current should be shut off as soon as possible after the car has attained full speed; and the car should be allowed to drift without current as long as possible before the brakes are applied. In this way the energy stored in the car will propel it at nearly maximum speed for a considerable distance between stops; there will be the smallest possible waste of energy in the brake shoes; and the losses of energy which take place when the current is in the motors will be prevented as far as possible. Practical tests as well as theoretical calculations show a possibility of very material saving in energy in the operation of an electric railway car or train, by the observance of this simple rule of drifting as much as possible and using the brakes as little as possible. Whatever energy is used up in the brake shoes is necessarily wasted. The smaller this waste can be kept while performing a given service, the greater the economy secured.

Sliding and Spinning Wheels. In accelerating a car, however, there is no economy in turning on current so rapidly as to spin the wheels. As mentioned in the section on "Brakes," the tractive effort between wheels and rails falls off about two-thirds when the wheels begin to slip; and this slipping of wheels, therefore, reduces the chance of securing the acceleration which is possible. For the same reason, in making emergency stops either by the use of brakes or by reversing the motors, care should be taken not to slide the wheels, as by so doing the time required to stop the car is much increased.

In the ordinary straight air-brake equipment used on heavy electric cars, there is much higher pressure carried in the storage reservoir than it is permissible to turn into the brake cylinder, since, if the full pressure were turned into the brake cylinder, it would result in sliding of the wheels—which, it has just been shown, is something to be avoided, not only on account of making flat spots on the wheels, but also because of the reduction in the braking force as soon as the wheels begin to slide. An experienced motorman can tell from the feeling of the car when the wheels are sliding, and will instantly release the brake sufficiently to allow the wheels to begin to revolve as soon as he notices that this has taken place.

The friction between brake shoes and car wheels decreases as the speed increases. A certain pressure applied to the brake shoes upon a car running 50 miles per hour, therefore, exerts much less retarding force than the same pressure at ten miles per hour. In order to give the same braking or retarding force at higher speeds, the brakes must be applied harder than at the lower speeds. If they are applied at the maximum pressure possible without sliding the wheels at higher speeds, it is evident that this pressure must be reduced as the speed of the car is reduced, or the wheels will be "skidded." In the Westinghouse high-speed automatic air brake used on steam roads, this reduction of pressure is automatically accomplished.

TESTING FOR FAULTS.

Bond Testing. It is important to test the conductivity of rail bonds from time to time in order to determine if they have deteriorated so as to reduce their conductivity and introduce an unnecessary amount of resistance into the return circuits. One way of doing this is to measure the drop in potential over a bonded joint as compared with the drop in potential of an equal length of unbroken rail. To do this, an apparatus is employed whereby simultaneous contact will be made bridging three or more feet of rail and an equal length of rail including the bonded joint, as shown in Fig. 48, which illustrates the connections of a common form of apparatus where two milli-voltmeters are employed that measure the drop in voltage of the bonded and unbonded rail simultaneously. If the current flowing through the rail due to the operation of the cars were constant, of course one milli-voltmeter might be used, being connected first to one circuit and then to the other. The current in the rail, however, fluctuates rapidly, so that two instruments are necessary for rapid work. The resistance of the bonded joint is usually considerably more than that of the unbroken rail, and the milli-voltmeter used to bridge the joint consequently need not be so sensitive as that bridging the unbroken rail.

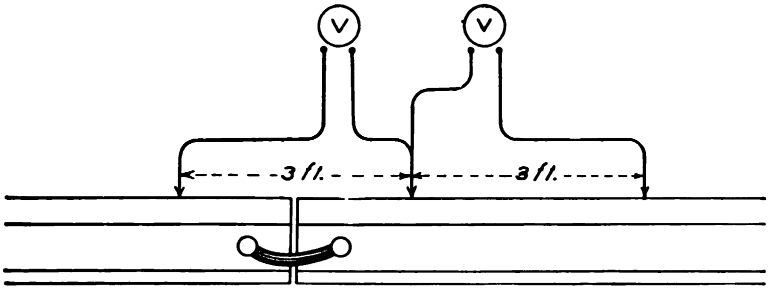

Fig. 48. Bond Testing.

In another form of apparatus, a telephone receiver is used instead of the milli-voltmeter, the resistance of a long unbroken rail being balanced against that of the bonded joint, as in a Wheatstone bridge, until, upon closing the circuit, these two resistances when balanced give no sound in the telephone receiver.

Bond tests of this kind can be made with satisfaction only when a considerable volume of current is flowing through the rails at the time of the test, because the drop in voltage is dependent on the current flowing, and in any event is small. It has sometimes been found necessary or advisable to fit up a testing car equipped with a rheostat which will itself use a considerable volume of current, so as to give a current in the rail which will give an appreciable drop of potential across a bonded joint. Some of the latest forms of testing cars carry motor generators which will pass a large current of known value through a bonded joint, and so cause a drop of potential across the joint large enough to be easily measured.

Motor-Coil Testing. Testing for faults in the motor-armature and field coils is done in a great variety of ways. The resistance of these coils can be measured by means of a Wheatstone bridge employing a telephone receiver in place of the galvanometer used in such bridges in laboratory practice; but other less delicate tests are also in use.

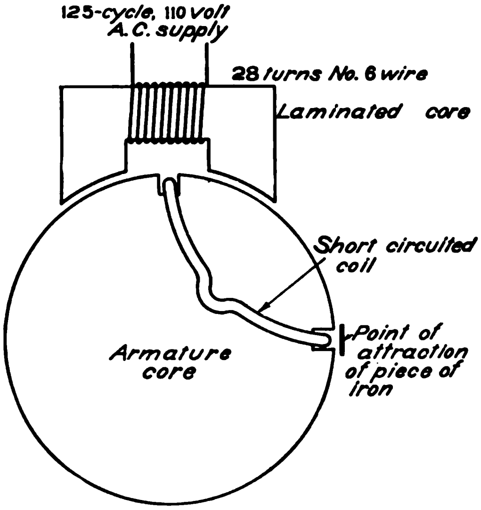

Fig. 49.

Another method is to pass a known current through the coil to be tested and to measure the drop in the voltage between the terminals of the coil, the voltage divided by the current equaling the resistance.

A simple method, and one which involves no delicate instruments, has lately been introduced into railway shop practice very successfully. This is known as the **transformer test** for short-circuited coils. It requires an alternating current which can easily be supplied either by a regular motor generator or by putting collecting rings onto an ordinary direct-current motor and connecting these rings to bars of opposite polarity on the commutator.

The method of testing for short-circuited armature coils employed in the shops of the St. Louis Transit Company is indicated in diagram in Fig. 49. A core built up of soft laminated iron is wound with 28 turns of No. 6 copper wire. This coil is supplied with alternating current from a 110-volt circuit. The core has pole pieces made to fit the surface of the armature. When one side of a short-circuited coil in the armature is brought between the pole pieces of this testing transformer, as in Fig. 49, the short-circuited armature coil becomes like the short-circuited secondary of a transformer, and a large current will flow in it. This current will in time manifest itself by heating the coil; but it is not necessary to wait for this, as a piece of iron held over that side of the coil not enclosed between the pole pieces, as indicated in Fig. 49, will be attracted to the face of the armature if held directly over the coil, but will be attracted at no other point.

This testing can be done very rapidly, and does not require delicate instruments or skilled operators.

Tests for short circuits in field coils can be made in a similar manner, by placing the coils on a core which is magnetized by alternating current. The presence of a short circuit, even of one convolution of a field coil, will be apparent from the increase in the alternating current required to magnetize the core upon which the field coil is being tested.

The insulation resistance of armatures and fields is frequently tested by means of alternating current, about 2,000 volts being the common testing voltage for 500-volt motor coils. One terminal of the testing circuit is connected to the frame of the motor, and the other to its windings. Any weakness in the insulation insufficient to withstand 2,000 volts will, of course, be broken down by this test. Alternating current is generally used for such tests because it is usually more easily obtained at the proper voltage, as it is a simple matter to put in an alternating transformer which will give any desired voltage and which can be controlled by a primary circuit of low voltage.

Open circuits in the armature can be easily detected by placing the armature in a frame so that it can be rotated, the frame being provided with brushes resting 90° apart on the commutator. If either an alternating or direct current be passed through the amature by means of these brushes, and the armature be rotated by hand, a flash will occur when the open-circuited coils pass under the brushes. A large current should be used.

The tests just mentioned are among the best of the methods used by electric-railway companies for systematic work in the location of certain classes of faults. A large number of other methods of testing have also been evolved.

The following are some of the most common faults experienced with electric railway car equipments:

Grounds. As one side of the circuit is grounded, any accidental leakage of current from the car wiring or the motors to ground will cause a partial short circuit. Such a ground on a motor will manifest itself by blowing the fuse or opening the circuit-breaker whenever current is turned into the motor. In case the fuse blows when the trolley is placed on the wire and the controller is off, it is a sign that there is a ground somewhere in the car wiring outside of the motors. Moisture and the abrasion of wires are the most common causes of grounds in car wiring. In motors, defects are usually due to overheating and the charring of the insulation.

Burn-Outs. Burning-out of motors is due to two general causes: First, a ground on the motor, which, by causing a partial short circuit, causes an excessive current to flow; second, overloading the motor, which causes a gradual burning or carbonizing of the insulation until it finally breaks down.

Short-circuited field-coils having a few of their turns short-circuited, if not promptly discovered, are likely to result in burned-out armatures, as the weakening of the field reduces the counter-electromotive force of the motor, so that an abnormally large current flows through the armatures. Cars with partially short-circuited fields are likely to run above their proper speed, though, if only one motor on a four-motor equipment has defective fields, the motor armature is likely to burn out before the defect is noticed from the increase in speed.

Sparking at the Commutator. As railway motors are made to operate, and usually do operate, almost sparkless, sparking at the brushes may be taken as a sign that something is radically wrong.

The pressure exerted by the spring in the brush holder may not hold the brush firmly against the commutator.

If brushes are burned or broken so that they do not make good contact on the commutator, they should be renewed or should be sandpapered to fit the commutator.

A dirty commutator will cause sparking.

A commutator having uneven surface will cause sparking, and should be polished off or turned down.

Sometimes the mica segments between commutator-bars do not wear as fast as the bar ; and when this is the case, the brushes will be kept from making good contact when the commutator-bars are slightly worn. The remedy is to take the armature into the shop, and groove out the mica between the comutator-bars for a depth of about $\frac{1}{64}$ inch below the commutator surface.

A greenish flash which appears to run around the commutator, accompanied by scoring or burning of the commutator at two points, indicates that there is an open-circuited coil at the points at which the scoring occurs.

The magnetic field may be weakened by a short circuit in the field-coils, as before explained, and this may give rise to sparking.

Short circuits in the armature may give rise to sparking, but will also be made evident by the jerking motion of the car and the blowing out of the fuse.

Failure of Car to Start. The failure of the car to start when the controller is turned on may be due to any of the following causes :

Opening of the circuit-breaker at the power house.

Poor contact between the wheels and the rails owing to dirt or to a breaking of the bond wire connections between the rail on which the car is standing and the adjacent track.

One controller may be defective in that one of the contact fingers may not make connection with the drum. In this case, try the other controller if there is another one on the car.

The fuse may be blown or the circuit-breaker opened. The occurrence of either of these, however, is usually accompanied by a report which leaves little doubt as to the cause of the interruption in current.

The lamp circuit is always at hand for testing the presence of current on the trolley-wire or third rail. If the lamps light when the lamp-circuit is turned on, it is a tolerably sure sign that any defect is somewhere in the controllers, motors, or fuse-boxes, although in case the cars are on a very dirty rail enough current might leak through the dirt to light the lamps, but not sufficient to operate the cars. In such a case, the lamps will immediately go out as soon as the controller is turned on. Ice on the trolley-wire or third rail will have the same effect as dirt on the tracks.

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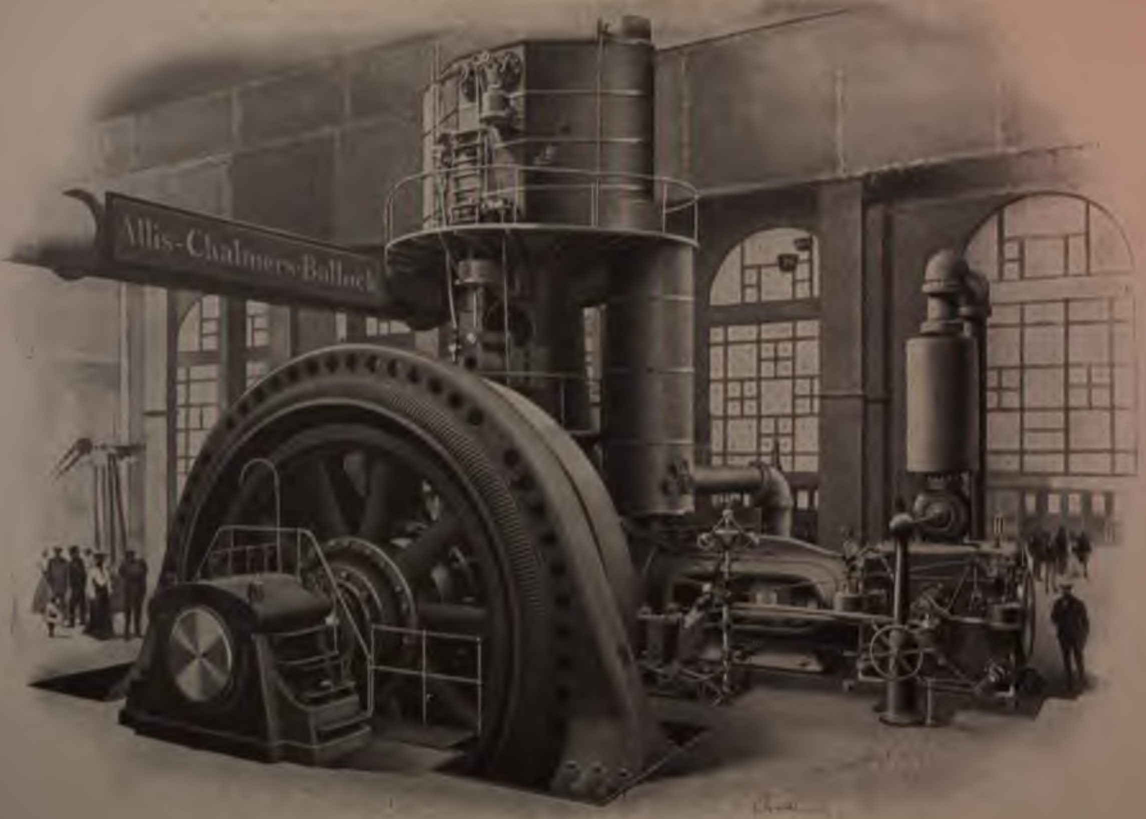
ASTOR, LENOX
TILDEN FOUNDATIONS



5,000 H.P. ALLIS-CHALMERS ENGINE. DIRECT-CONNECTED TO GENERATOR.

Carries 5,600 H.P. with 15 inches vacuum.

Machinery Hall, World's Fair, St. Louis.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

The object of this instruction paper is to set forth the most important features which must be considered in the actual handling and operation of electric generators and motors. The principles and general construction of direct-current (D. C.) and alternating-current (A. C.) generators and motors, are treated elsewhere.

The subject may be divided into three parts as follows:

A. The Selection, Erection, Connection, and Operation.
B. The Inspection and Testing.
C. The Troubles or "Diseases" and Remedies.

SELECTION OF A MACHINE.

The voltage, capacity, and type of machine are dependent upon the system to which it is to be connected, and the purpose for which it is to be utilized, but there are certain general features which should be considered in every case.

Construction. This should be of the most solid character and guaranteed first-class in every respect, including materials and workmanship.

Finish. A good finish is desirable, since it is likely to cause the attendant to take greater care of the equipment.

Simplicity. The machine should be as simple as possible in all its parts; peculiar or complicated features should be avoided, unless absolutely essential for the operation of the system.

Attention. The amount of attention required by the machine should be small. The number of screws or nuts should be reduced to a minimum, and they ought always to be provided with some locking device to prevent them from becoming loose. The brushes should be capable of being easily adjusted and self-feeding, so that they may "follow" or make up for any trifling eccentricity of the commutator. The bearings should be self-oiling, and in the smaller sizes self-aligning.

Handling. An eye-bolt or other means by which the machine can be easily lifted and moved is desirable. It ought to be possible to take out the armature conveniently by removing one of the bearings, or the tops of the field magnet, frame and bearings, or by moving the halves sideways if the frame is split vertically. The armature and field windings should be so designed and mounted that their removal for repairs is an easy matter.

Interchangeability. The machine selected should preferably be one of a regular and standard type, so that extra parts can be obtained without needless delay.

Regulation. Some form of regulating device should be provided by means of which the E. M. F. or current of a generator, or the speed, and in some cases the direction of rotation of a motor, can be readily and accurately controlled.

Form. The machine should be symmetrical, well-proportioned, compact and solid in form. The large and heavy portions should be placed as low as possible, to give greater stability.

Weight. It is a mistake to select a very light machine when it is for stationary use, since weight increases its strength, stability, and durability.

Capacity. This should be ample for the work to be done; in fact it is advisable to allow a margin for increase. The machine should be provided with the maker's name-plate, specifying the rated current, voltage, speed and capacity. The manufacturer should also guarantee the following: That the machine does not heat up in any part of its windings, to more than 50° C, after a run of six hours' duration, under rated load conditions;* also that it is able to carry a 25 per cent overload for two hours, and momentary overloads of 50 per cent, without excessive heating or sparking.

Cost. It is usually an error to select a generator or motor simply because it is cheap, since both the materials and workmanship required for the construction of a high-grade electrical machine are costly.

MECHANICAL CONDITIONS.

Location. The place chosen for the machine should be *dry, free from dust or grit, light, and well ventilated.* It must also be arranged so that there is room enough for the removal of the armature without shifting or turning the machine.

Foundations. It is of great importance to have the machine firmly placed upon a good and solid foundation; otherwise, no matter how well constructed and managed, the vibrations occurring on a poor foundation will produce sparking at the brushes, and its accompanying troubles.

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* NOTE. By resistance measurements.

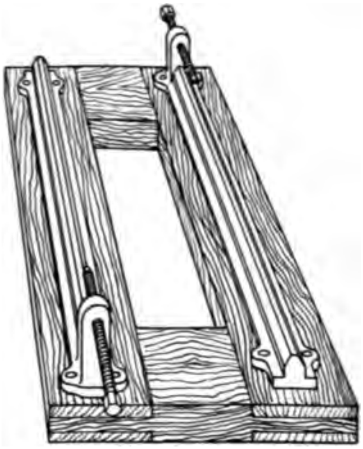

Fig. 1.

It is also necessary, if the machine is belt-driven, to mount it upon rails or a sliding bed-plate provided with holding-down bolts and tightening screws for aligning and adjusting the belt while the machine is in operation. (See Fig. 1). The machinery foundations consist of a mass of stone, masonry, brickwork, or concrete, upon which the machinery is placed and usually held firmly in place by bolts passing entirely through the mass. These bolts are built into the foundations, the proper position for them being determined by a wooden template suspended above the foundation, as shown in Fig, 2. The bolts are preferably surrounded by iron pipe that fixes them longitudinally but allows a little side play which may be necessary to enable them to enter the bed-pla

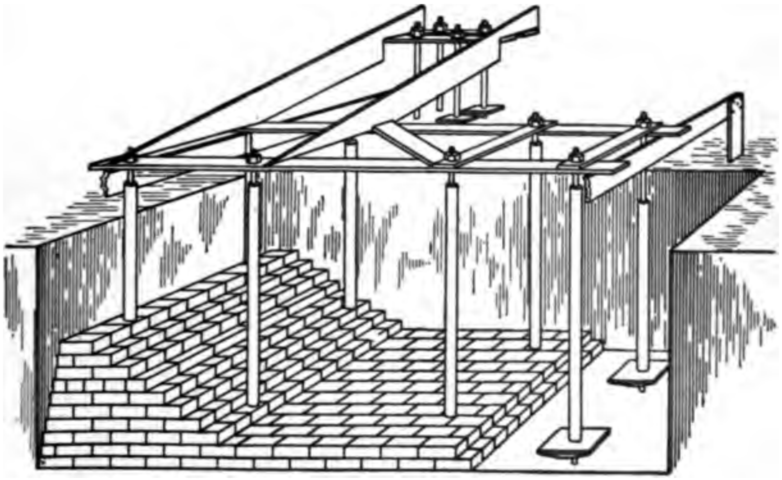

Fig. 2.

holes readily. The brickwork for machinery foundations should consist of hard burned bricks of first quality, *laid in good cement mortar.* Ordinary *lime mortar is entirely unfit* for the purpose, being likely to crumble away under the effect of the vibrations caused by the machinery. Brick or concrete foundations should be finished with a cap of bluestone or cement. This tends to hold the foundation together, and forms a level surface upon which to set the machinery. If the engine and generator are provided with a cast-iron sub-base, the capping may be dispensed with.

Fixing the Machine. In fixing either direct-connected or belt-driven machines, first determine, with a long straight edge and spirit level, if the top of the foundation is level and true. If this is found to be the case, the holding-down bolts may be dropped into the holes in the foundation, if they are not already built in, and the machine carefully placed thereon, the ends of the bolts being passed through the holes in the bed-plate and secured by a few turns of the nuts. The machine should then, if belt-connected, be carefully aligned with the transmitting pulley or fly wheel. Particular attention should be paid to the alignment of the pulleys in order that the belt may run properly. If direct-connected, the dynamo bed-plate and armature shaft must be carefully aligned and adjusted with respect to the engine shaft, raising or lowering the bed-plates of the corresponding machines by means of thin cast-iron or other wedges; and the generator frame should also be adjusted to its proper height by means of thin strips of metal or fiber set between its supporting feet and the bed-plate. Having thus aligned and leveled the machine, it should next be grouted with thin cement. This is done by arranging a wall of mud or wooden battens around the bed-plates of the machines, and running in thin cement until the holding-down bolt holes are filled, and the cement has risen to the level of the under side of the bed-plate. When the cement has set, the wall may be removed and the nuts on the holding-down bolts drawn up. This firmly fixes the machine upon its foundation.

Mechanical Connections. Various means are employed to connect the engine or other prime mover with the generator, or the motor with the apparatus to be driven. The most important are as follows:

Direct Connection.
Belting.
Rope Driving.
Toothed Gearing.

Other apparatus, such as shafting, clutches, hangers and pulleys, are used in connection with the above means.

Direct Connection. This is the simplest, and for that reason the most desirable, means of connection, provided it can be carried out without involving sacrifices that offset its advantages. This method, also called direct coupling or direct driving, compels the engine and generator to run at the same speed, which gives rise to some difficulty, as the most desirable speeds of the two machines do not usually agree. The natural speed of a generator is high, while that of an engine is low; hence to obtain the same voltage from a direct-connected generator, more inductors are necessary, or the flux cut must be increased. Accordingly, the armature and frame of the direct-connected generator must be larger, thus making it a more expensive machine than the belt-driven.

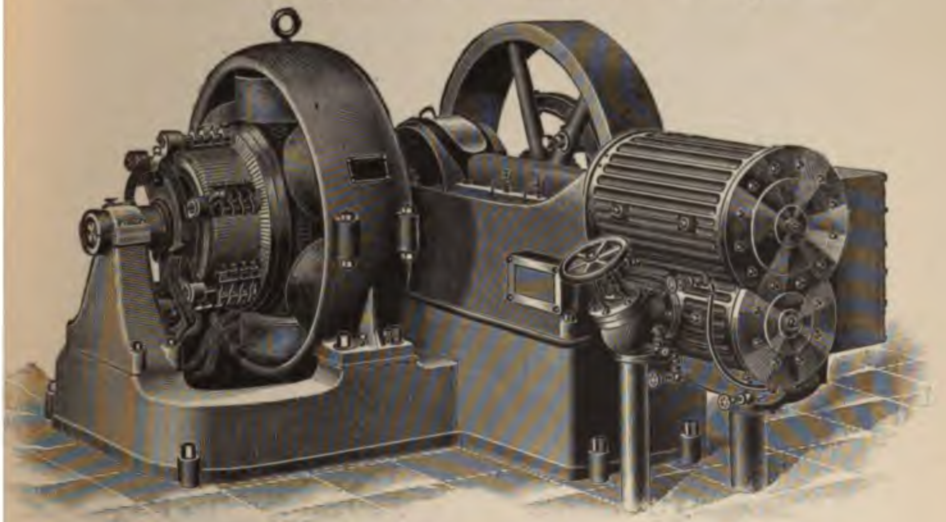

Fig. 3.

The direct connection of an engine and generator is accomplished in several ways, the simplest of which consists in mounting the armature of the generator directly on one end of the shaft of the engine. This may be accomplished in any one of several ways. Fig. 3 represents the three-bearing method. Two-and-four-bearing methods are also used. These secures the great advantages: that accurate alignment is readily obtained, and space occupied reduced to a minimum, and the mounting of the bearings on a common sub-base avoids trouble due to unequal settling.

Another form of direct coupling is that in which an engine and a generator, each complete in itself, and each having two bearings, are coupled together by some mechanical device, which may be either rigid or slightly elastic or adjustable. In the former case the two shafts are practically equivalent to a single one, which, while making it easy to remove either machine for repairs, is somewhat objectionable owing to the fact that it requires larger foundations, and introduces the difficulty of accurately aligning four bearings. The use of a flexible coupling avoids the necessity of perfect alignment, and also the serious trouble that might arise if the settling or the wear of the bearings should be uneven. There are various forms of flexible coupling. One of the forms manufactured by the Westinghouse Machine Company is shown in Fig. 4, the flexibility being provided by the springs which hold the two parts of the coupling together.

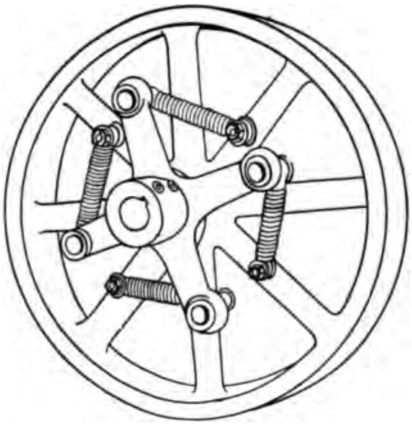

Fig. 4.

The direct coupling of generators with turbines can be carried out without departing from the natural speed of either machine, since the ordinary speed of a turbine agrees closely with the normal speed of a generator of the corresponding capacity.

The relative efficiency of direct coupling and belting depends greatly upon the conditions; but in general the former is more efficient at or near rated load, and the latter at light loads. *The simplicity, compactness, and positive and noiseless action of direct connection* have caused it to become the most approved method.

Belting. If the generator or motor is not directly connected, one to the prime mover and the other to the apparatus to be driven, they are usually connected by some form of belting. The kind of belting selected depends greatly upon conditions of drive, distances, etc.; and it may be leather, rawhide, rubber, or rope. For ordinary short drives, leather is the most desirable, though, when the power to be transmitted is small, rawhide belts are also satisfactory, especially as the cost is less than for leather belts. For considerable distances, rope driving answers very well because it is so much lighter and cheaper than an equivalent leather belt, though grooved pulleys are required, making the total cost about the same. Rubber belts are used to advantage in driving generators from water turbines, where the belt might be exposed to moisture. Leather belting is usually the most reliable and satisfactory for general application, except for very short drives, where a form of chain belt works best. There are three thicknesses of leather belting—single, light-double, and double. For use in connection with generators, motors, or other high-speed machinery, the "light-double" belting is usually the best.

The exact amount of power that a given belt is capable of transmitting is not very definite. The ordinary rule is that "single" belt will transmit 1 horse-power for each inch of its width when traveling at a speed of 1,000 feet per minute. If the speed is greater or less, the power is proportionately increased or decreased. The statement of H. P. transmitted is based upon the condition that the belt is in contact with the transmitting pulley around one-half of its circumference, or 180°, which is usually the case. If the arc of contact is less than 180°, the power transmitted is less in the following proportion: An arc of 135° gives 84 per cent, while 90° contact gives only 64 per cent of the power derived from a belt contact of 180°. If on the other hand, the upper side sags downward, which is always desirable, the belt is in contact with more than half the circumference of the pulley; and thus the grip is considerably increased and more power can be transmitted. These facts make it very desirable to have the *loose side of the belt on top.* If the loose side is below, it sags away from the pulley and is also likely to strike the floor.

The complete expression for determining the width of a single belt required to transmit a given horse-power is as follows:

$$W = \frac{\text{H. P.} \times 1{,}000}{S \times C},$$

where W is the width of the belt in inches; H. P. the horse-power to be transmitted; S the speed of the belt in feet per minute, which is equal to the circumference of the driving pulley in feet multiplied by the number of revolutions per minute;* and C a factor dependent upon the arc of contact.

"Double" belting is expected to transmit one and one-half ($1\frac{1}{2}$), and "light-double" one and one-quarter ($1\frac{1}{4}$) times as much power as "single" belting of the same width. Belting formulas are only approximate, and should not be applied too rigidly, since the grip of the belt upon the pulley varies considerably under different conditions of tension, temperature and moisture. The smooth side of a belt should always be run against the pulley, as it transmits more power and is more durable. Belting used for electric machinery, being usually high-speed, should be made "endless" for permanent work, as this makes less noise; but it may be used with laced joints, temporarily. A spliced or "endless" joint is made as follows:—Both ends of the belt are pared down on one side (opposite) with a sharp knife, into the form of a long thin wedge, so that when laid together a long uniform joint is obtained of the *same thickness as the belt itself*. The parts are then firmly joined with cement and sometimes with rivets also. It may be necessary to splice or lace a belt while in position on the pulleys; and for this purpose some form of belt clamp (Fig. 5) should be employed.

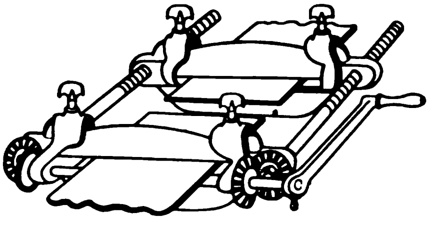

Fig. 5.

If a belt is ordered endless, or is spliced away from the pulleys, great care should be exercised in determining the exact length required. A string that will not stretch, or preferably a wire put around the pulleys in the position to be occupied by the belt, is the best way to avoid a mistake. In measuring for a belt, the generator or motor should be moved on its sliding base so as to make the distance between shaft centers a minimum, in order to allow for the stretch of the belt, which may be as much as ½ inch per foot of length.

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* NOTE. Belts slip or "creep" on the pulley about 2 per cent; hence, in determining the size of pulleys whose speed must be accurate, the calculated belt speed should be about 2 per cent too high.

The lacing of a belt is a very simple and common method of making a joint; but should not be permanently employed at high speeds for electric machinery belting, as it is liable to pound on the pulleys, producing noise, vibration and sparking; and in the case of generators it is also likely to cause flickering in the lamps. In lacing belts, the ends should be cut *perfectly square, and there should be as many. stitches of the lace slanting to the left as there are to the right;* otherwise the ends of the belt will shift sidewise owing to the unequal strain, and the projecting corners may strike or catch in the clothing of persons. A good way to accomplish this is shown in Fig. 6. The various holes should be made with a circular punch, the nearest one being about ¾ inch from the side, and the line through the center of the row of holes about 1 inch from the end of.the belt. In large belts these distances should be a little greater. A regular belt lacing of strong pliable leather or a special wire is used. The lacing is doubled to find its middle; and the two ends are passed through the two holes marked "*1*" and "*1a*," precisely as in lacing a shoe. The two ends are then passed successively through the two series of holes, in the order in which they are numbered, *2*, *3*, *4*, etc., and *2a*, *3a*, *4a*, etc., finishing at *13* and *13a*, which are additional holes for securing the ends of the lace. The great advantage of this method of lacing is that the lace lies on the pulley side perfectly parallel to the direction of motion.

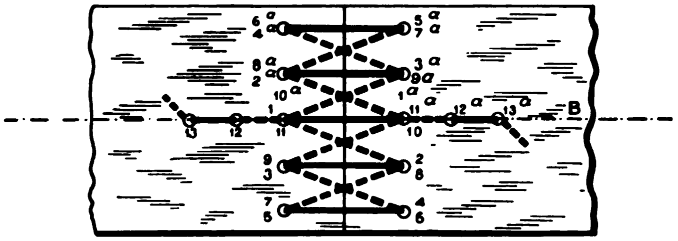

Fig. 6.

Perforated belts are often employed for the reason that a film of air is likely to be imprisoned between the belt and the pulley, thus preventing a good grip. Hence small perforations are sometimes made in the belt, especially for high-speed operation (3,000-5,000 feet per minute), to allow the air to escape; and since these are in the form of narrow slits, with their greatest dimension in the direction of motion, they do not materially reduce the strength of the belt.

Arrangement and Care of Belting. It is very desirable, for satisfactory running, that belts should be reasonably long and nearly horizontal. The distance between the centers of two belt-connected pulleys should be not less than 3 times the diameter of the larger pulley. The belt should be just tight enough to avoid slipping, without straining the shaft or bearings. The two shafts which are to be belt-connected must be perfectly parallel, and the centers of the face of the driving and driven pulleys must be exactly opposite to each other, in a straight line perpendicular to the axis of the shafts. The machines should then be turned over slowly with the belt on, to see if the latter tends to run to one side of the pulley, which would show that it is not yet properly "lined up," in which case one or both machines should be slightly shifted, until the belt runs properly. If possible, the machine and belt should be set and adjusted so as to cause the armature to move back and forth in the bearings while running, on account of the side motion of the belt, and thus make the commutator wear more smoothly, and distribute the oil in the bearings.

It is always desirable to have belts as pliable as possible; hence the occasional use of a good belt dressing—as neatsfoot oil, etc.—is recommended. Rosin and other sticky substances are sometimes applied to increase the adhesion; but this is a practice allowable only in an emergency, as it may destroy the belt surface.

In places where the belting is very much exposed, and liable to catch in the clothing of any person, it is advisable to surround it by a railing or box.

Rope Driving possesses advantages over ordinary belting in some cases. The rope runs in V-shaped grooves in the peripheries of the pulleys, and thereby obtains a great grip by a sort of wedging action. The kinds of rope ordinarily employed for this purpose are cotton, hemp, rawhide and wire. The general advantages are:

1. Economy in cost.

2. Large amount of power that can be transmitted with a given diameter and width of pulley, on account of the grip obtained.

3. It is almost noiseless.

4. Ropes, on account of their lightness, can be used to transmit power over greater distances than are possible with any other form of belting; and also for very short distances on account of the wedging action. Manila rope is generally used in the United States, being of three strands, hawser laid, and may be from ½ inch to 2 inches in diameter. The breaking strength varies from 7,000 to 12,000 pounds per square inch of cross-section. It has been found that the best results are obtained when the tension in the driving side of the rope is only 3 to 4 per cent of the breaking strength.

The diameter of a single rope necessary to transmit a required H. P. is given by the formula:

$$D^2 = \frac{825 \text{ H.P.}}{V\left(200 - \frac{V^2}{1,072}\right)},$$

in which H. P. = horse-power transmitted;
V = velocity of rope in feet per second;
D = diameter of rope in inches.

The maximum power is obtained at a speed of about 84 feet per second. With higher speeds the centrifugal force becomes so great that the power transmitted decreases rapidly, and at about 142 feet per second it counteracts the whole allowable tension (200 D^2 pounds) and no power is transmitted.

Arrangement of Rope Belting. There are two methods of arranging rope transmission: one consists in using several separate belts; and the other employs a single endless rope which passes spirally around the pulley several times and is brought back to the first groove by a slanting idle pulley, and therefore is called the "wound" system. The separate ropes do not require the carrying-over pulley, and if one rope breaks, those remaining are sufficient to transmit the power temporarily; whereas an accident with the single-rope system entirely interrupts the service. In the "multi-rope" system it is practically impossible to make and maintain the belts of exactly equal length, hence the tensions on the various ropes differ, and they hang at different heights on the slack side, producing an awkward appearance.

Toothed Gearing possesses the decided advantages of positive action and the ability to give large ratios of speed and small side pressure on the bearings. Nevertheless it is seldom employed for driving generators. As the most extensive applications of gearing for electrical purposes are in connection with railway motors, it will be taken up under that heading.

SHAFTING.

An intermediate or counter shaft is not desirable since it increases the complication and frictional losses of the system; but it is often necessary in the generation or application of electric power, either to obtain a greater multiplication of speed than is possible by belting directly, or to enable a single engine or motor to drive a greater number of machines.

The two important kinds of shaftings are "cold-rolled" and "turned." The former is rolled to the exact size and requires no further treatment. It has the advantage of a smooth, hard surface, but it is difficult to make perfectly true and straight. Turned-steel shafting is most commonly employed, and has the advantage that shoulders, journals, or other variations in size can be easily made on it. The following table gives the ordinary data for shafting:

TABLE I.

Shafting.

Diameter in inches.	Weight lbs. per ft.	Allowable H. P. transmitted at 100 r. p. m.	Width of key seat in inches.
$1\frac{7}{16}$	5.5	4.3	$\frac{3}{8}$
$1\frac{15}{16}$	10.	10.	$\frac{1}{2}$
$2\frac{7}{16}$	15.8	20.	$\frac{3}{4}$
$2\frac{15}{16}$	23.	34.	$\frac{3}{4}$
$3\frac{7}{16}$	31.5	54.	$\frac{7}{8}$
$3\frac{15}{16}$	41.	80.	1
$4\frac{7}{8}$	62.8	156.	1
$5\frac{7}{8}$	91.1	270.	1

With speeds greater than 100 r. p. m., the allowable H. P. varies directly in proportion to the speed employed.

ASSEMBLING OF THE MACHINE.

In unpacking and putting the machine together, great care should be used to avoid the least injury to any part, to clean scrupulously each part, and to put the parts together in exactly the right way. This care is particularly important with regard to the shaft, bearings, magnetic joints, and electrical connections, from which every particle of grit, dust, metal chips, waste, etc., should be removed. It is advisable to study carefully the blue prints or instruction matter usually sent with each machine, before attempting to put it together. The armature must be handled with great care in order not to injure the wires and their insulation as well as the commutator and shaft. The armature should be handled as far as possible by the shaft, and when it must be placed on the ground a pad of cloth or layer of boards should be interposed. A convenient form of sling for handling armatures with their shafts in position is shown in Fig. 7. The bearings should be carefully cleaned, set in exactly the right positions, and firmly secured. The tops should be left loose for a short time, so that the tendency to heat up at the first run may be decreased; and after that they

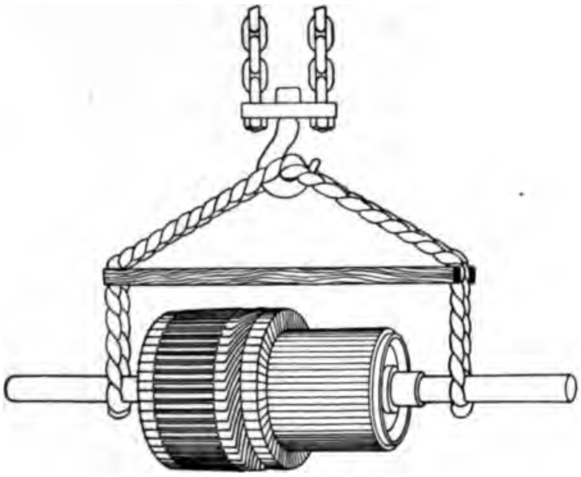

Fig. 7.

should be drawn up tight. The field frame should be set so that the air gap is the same for all pole pieces, as otherwise the machine will be magnetically unbalanced and tend to spark badly.

The adjustment of the brushes, etc., should preferably be left until the machine is electrically connected and ready to receive its trial run.

METHODS OF WIRING.

Before laying the wires, the circuits should be carefully mapped out and the work so planned as to secure the simplest arrangement. The wiring should then be installed neatly and in accordance with the rules of the National Board of Fire Underwriters and of the local department having supervision. Otherwise unnecessary trouble, delay and expense may be incurred.

The wire may be installed in one of two general methods, *viz.*:

Exposed on	Cleats. Knobs. Bushings.
Concealed in	Wooden moulding. Iron conduit. Terra cotta conduit.

The wire should preferably be either rubber-covered or made up in the form of lead cables. Exposed wires possess the advantages of cheapness, as well as accessibility for inspection and repair; and any short circuit or ground is readily seen and removed, whereas it might cause great uncertainty and delay when the wires are concealed.

Concealed conductors, especially where they are placed under the floor, have the great advantage over exposed wiring, in that they are entirely out of the way. This is especially important in large installations, where overhead traveling cranes are almost a necessity.

When alternating-current conductors are enclosed in iron conduits, both wires of each phase, or all the wires, must be run in the same duct, otherwise the inductance would be excessive.

All conductors, including those connecting the machine with the switchboard, as well as the bus bars on the latter, should be of ample size to be free from overheating and excessive loss of voltage. The drop between the generator and switchboard should not exceed ½ per cent at full load, because it interferes with proper regulation and adds to the less easily avoided drop on the distribution system.

The safe carrying capacities of copper conductors as recommended by the Board of Fire Underwriters, are given in the following table:

TABLE II.

Safe Carrying Capacities of Copper Wires.

B. & S. G.	Rubber Insulation. Amperes.	Other Insulations. Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
Circular Mils.			
200,000	200	300	
300,000	270	400	
400,000	330	500	
500,000	390	590	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
1,700,000	930	1,490	
1,800,000	970	1,550	
1,900,000	1,010	1,610	
2,000,000	1,050	1,670	

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

The carrying capacity of Nos. 16 and 18, B. & S. gage wire is given, but no smaller than No. 14 is to be used.

The safe carrying capacity of insulated aluminum wire is 84 per cent of that given for copper wires of corresponding size and insulation.

Switches are devices for closing and opening the various circuits or branches of an electrical distribution system. A knife switch should always be employed when the capacity of the circuit to be controlled exceeds 10 amperes. It may be single-, double-, or triple-pole; single- or double-throw; and with or without fuses as desired. If the rated capacity of a switch exceeds 25 amperes, its terminals must be provided with lugs into which the ends of the conducting wires should be soldered. The principal parts of a knife switch (Fig. 8) are the *base* (*a*), which must consist of a non-combustible, non-absorptive insulating material; the *hinges* (*b*), which carry the *blades* (*c*); the contact *jaws* or *clips* (*d*); the insulating *cross-bar* (*e*); and the *handle* (*f*). The hinges, blades and jaws should be made of pure copper, of sufficient cross-section to insure mechanical stiffness and proper carrying capacity, and their contact surfaces must not be less than 1 square inch per 75 amperes of the rating. The hinges and contact jaws must be springy enough to insure good contact with the blades. The blades and jaws must be so shaped that they open along their entire length simultaneously; otherwise the arc which is formed upon opening a loaded circuit, will burn off the last points of contact. In fact this arc, when produced by a heavy current, is very difficult to control; and switches should never be opened on heavily-loaded circuits except in an emergency. In practice, however, some form of electro-magnetic circuit-breaker is employed for the purpose, and may be operated automatically with overload, or by hand at any time.

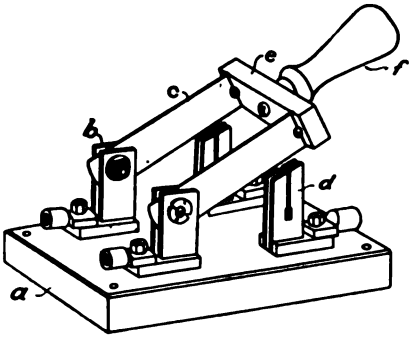

Fig. 8.

Knife switches should be so placed that *gravity tends to open* rather than to close them. They should always be located in dry, accessible places and grouped as far as possible. If located in ex-

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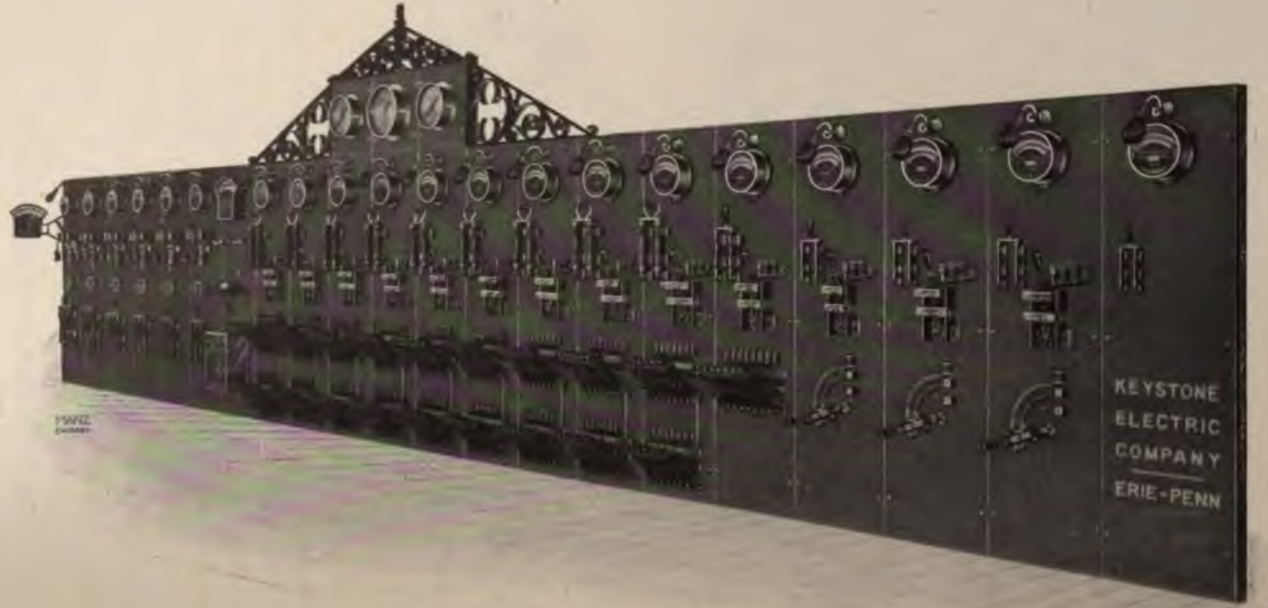


SWITCHBOARD OF THE WHITEHALL PORTLAND CEMENT CO.

Built and Installed by the Keystone Electric Co.

posed positions they should be enclosed in slate or equivalently lined cabinets. The distances between the parts of opposite polarity, in an approved knife switch, must never be less than the values given in the following table:

TABLE III.

Switch Data.

125 VOLTS OR LESS:	Minimum Separation of Nearest Metal Parts of Opposite Polarity.	Minimum Break-Distance.
For Switchboards and Panel Boards—		
10 amperes or less	¾ inch	½ inch.
11-25 "	1 "	¾ "
26-50 "	1¼ "	1 "
For Individual Switches—		
10 amperes or less	1 inch	¾ inch.
11- 35 "	1¼ "	1 "
36- 100 "	1½ "	1¼ "
101- 300 "	2¼ "	2 "
301- 600 "	2¾ "	2½ "
601-1,000 "	3 "	2¾ "
126 TO 250 VOLTS:		
For all Switches--		
10 amperes or less	1½ inch	1¼ inch.
11- 35 "	1¾ "	1½ "
36- 100 "	2¼ "	2 "
101- 300 "	2½ "	2¼ "
301- 600 "	2¾ "	2½ "
601-1,000 "	3 "	2¾ "

On switchboards, the above spacings for 250 volts direct current are also approved for 440 volts alternating current. Switches on switchboards with these spacings intended for use on alternating-current systems with voltages above 250, must be stamped with the voltage for which they are designed, followed by the letters "A. C."

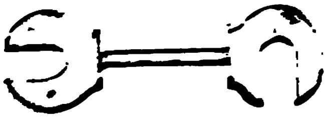
251 TO 600 VOLTS:		
For all Switches—		
10 amperes or less	3½ inch	3 inch.
11- 35 "	4 "	3½ "
36-100 "	4½ "	4 "

Auxiliary breaks or the equivalent are recommended for switches designed for over 300 volts and less than 100 amperes, and will be required on switches designed *for use in breaking currents* greater than 100 amperes at a pressure of more than 300 volts.

[illegible]

[illegible]

[illegible]



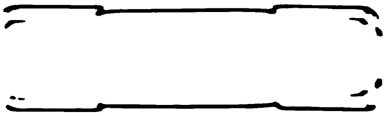


Fig. [illegible]

[illegible] With large [illegible] and the use of en-[illegible] whenever the rating of [illegible]

[illegible] have a casing around the fusible ma-[illegible] dangerous spattering and which also [illegible] to form whenever a fuse blows.

[illegible] should always be employed when the size of the wire changes or where connections between any electrical apparatus and the conductors are made. They must be mounted on slate, marble, or porcelain bases; and all metallic fittings employed in making electrical contacts must have sufficient cross-section to insure mechanical stiffness and carrying capacity.

Electro-magnetic Circuit-Breakers or **Limit Switches** are frequently used in place of fuses to protect electrical circuits. Their general construction and application are indicated in Fig. 11. The current is led through a helix A the electro-magnetic action of which, when the current reaches a predetermined limit, automatically releases the blades from contact with the jaws and thus opens the circuit. The final break occurs at carbon tips, thus preventing destructive arcing at the copper contacts. Circuit-breakers possess the following advantages over fuses:

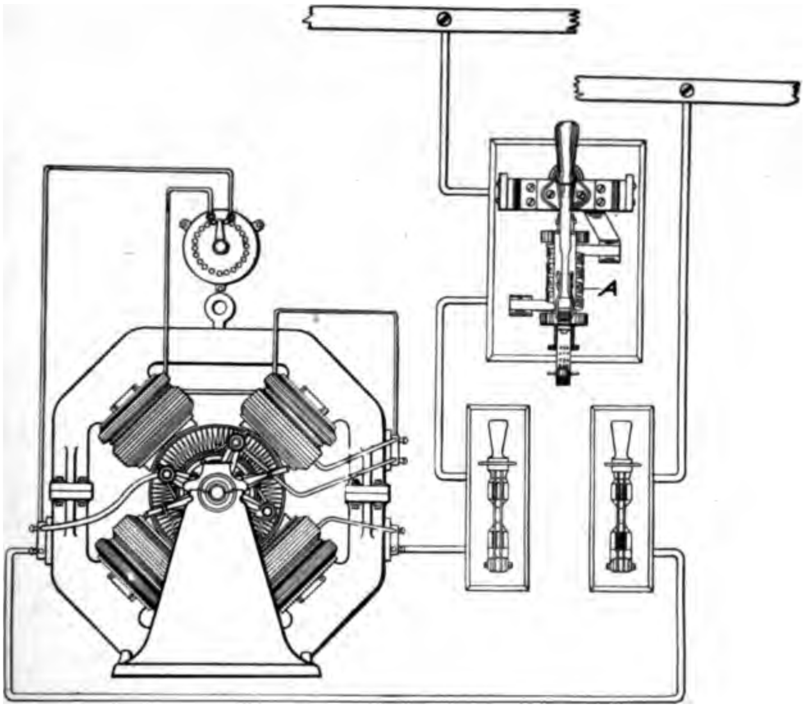


Fig. 11.

1. They can be employed as switches if desired.
2. They can easily be reset and thus put into condition for acting again.

3. Their range can be easily varied within considerable limits.

4. They can also be made to operate "tell tales" whenever the circuit they control is opened.

On account of these general advantages, their use is advisable on switchboards of systems that are liable to frequent overloads. The circuits, however, should, as a rule, be provided also with fuses, since it is possible that the circuit-breaker may fail to open, owing to corrosion or other cause.

Starting-Boxes should always be furnished with D. C. motors, for the following reason: If the line voltage should be applied directly to the terminals of the armature while it is standing still, a very excessive current would flow, since the resistance is low and no C. E. M. F. exists. Hence, to prevent injury to the winding, a resistance is inserted between one supply terminal and the armature in order to reduce the electromotive force at the motor terminals while it is speeding up, the resistance being gradually reduced until completely removed when rated speed is reached. All motor starting-boxes must also be provided with a **no-voltage release.** This consists of an electro-magnet in series with the shunt-field circuit, which holds the rheostat arm in the operating position as long as current flows through the shunt field from the line. If the line switch be opened or the shunt-field circuit accidentally broken, the device becomes demagnetized and releases the arm, which returns to its starting position (all resistance in circuit) by the action of a spring or of gravity. The starting-boxes of larger motors are also frequently equipped with **overload releases.** These, practically, are electro-magnetic circuit-breakers which open the supply lines if the motor becomes greatly overloaded. The general arrangement of switches, cut-outs and starting-boxes should be in accordance with the following extract from the Rules of the National Board of Fire Underwriters:

"Each motor and starting-box must be protected by a cut-out and controlled by a switch, said switch plainly indicating whether 'on' or 'off.' The switch and rheostat must be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the Inspection Department having jurisdiction.

"Where the circuit-breaking device on the motor-starting rheostat disconnects all wires of the circuit, this switch may be omitted.

"Overload-release devices on motor-starting rheostats will not be considered to take the place of the cut-out required if they are inoperative during the starting of the motor.

"The switch is necessary for entirely disconnecting the motor when not in use; and the cut-out, to protect the motor from excessive currents due to accidents or careless handling when starting. An automatic circuit-breaker disconnecting all wires of the circuit, may, however, serve as both switch and cut-out."

The **Various Kinds of Circuit** on which motors and generators are commonly used, and the best type of machine in each case, are as follows :

TABLE IV.

Types of Machine for Various Kinds of Circuits.

DIRECT-CURRENT, CONSTANT-POTENTIAL.

Circuits on which potential or voltage is kept constant; machines, lamps, etc., being run in parallel.

Currents intended for—	Potential.	Generator should be—	Motor should be—
Electro-metallurgy.	1 to 150 volts	Shunt-wound.	Not used.
Incandescent lighting.	110 to 125 volts (2-wire sys.) 220 to 250 volts (2-or 3-wire sys.)	Shunt- or compound-wound.	Shunt-wound for constant speed. Sometimes series- or compound-wound for variable speed.
Electric railway Electric power.	500 to 660 volts	Compound-wound.	Series-wound for railway. Shunt-wound for stationary.

DIRECT, CONSTANT-CURRENT.

Circuits on which current or amperes are kept constant; machines, lamps, etc., being run in series.

Circuits intended for—	Current in Amperes.	Generator should be—	Motor.
Arc lighting.	6.8 or 9.6	Series-wound with current regulator.	No longer used.

ALTERNATING-CURRENT, POLYPHASE.

Constant-potential, two- or three-phase currents.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor is—
Power transmission.	On the line, 5,000 to 60,000.	In the machines, varying 500 to 12,000	Separately excited.	Synchronous or Induction.

ALTERNATING-CURRENT, SINGLE-PHASE.

Almost always constant-potential.

Circuits intended for—	Potential in Volts.		Generator should be—	Motor should be—
Incandescent lighting. Arc lighting. Sometimes constant-current. Electric power.	Primary, 1,000 or more,	Secondary, 104 or 208.	Separately excited. Also sometimes composite-wound.	Synchronous. Induction. Series. Repulsion.

Diagrams of Connections are given for each important case to show what is actually required. These merely represent the path of the currents in the simplest way, the important thing being to have these paths right, and to know which parts or wires are to be connected. The case of plants operating with only a single generator will be first considered, and then the parallel or series operation of several machines described.

Shunt Dynamo, Supplying Constant-Potential Circuit. A machine of the above type is represented in Fig. 12, with the necessary connections. The brushes are connected to the two conductors forming the main circuit; also to the field-magnet coils S*h* through a resistance-box R, to regulate the strength of current and therefore the magnetism in the field. A voltmeter is also connected to the two brushes or main conductors, to measure the voltage or electrical pressure between them. One of the main conductors is connected through an ammeter A, which measures the total current on the main circuit. The lamps L, or motors M, are connected in parallel between the main conductors or between branches from them. This represents the ordinary low-tension system for electric light and power distribution from isolated plants or central stations

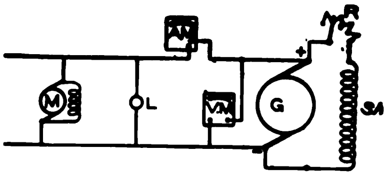


Fig. 12.

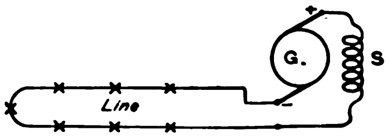


Fig. 13.

Series Dynamo Supplying Constant-Current Circuits. The connections in this case are extremely simple, the armature, field coils, ammeter, main circuit, and lamps all being connected in one series (Fig. 13), the current being kept constant. This system is used for series D. C. arc lighting.

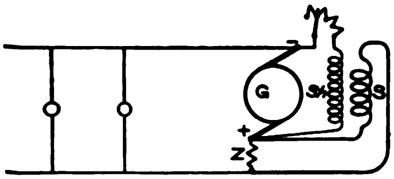


Fig. 14.

Compound Direct-Current Dynamo. This machine is a combination of the two foregoing types as regards field winding; but its load of lamps and motors are connected in parallel, as shown in Fig. 14. The resistance Z is known as the "series" shunt, and is for adjusting the percentage of compounding. The greater the resistance of Z, the greater the current passing through the series field, and the greater the compounding. This type of machine is most extensively employed in electric railway and in isolated plant work.

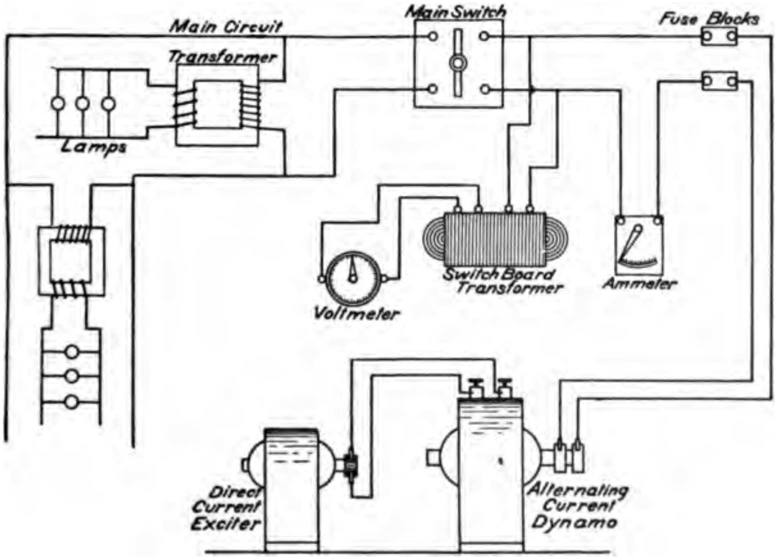


Fig. 15.

Alternating-Current Plants. The connections for a single-phase installation are shown in Fig. 15, in which the names of the different parts are given. This system is extensively used for lighting over considerable distances, but is not very well adapted for power application. The wiring of a two-phase system is essentially double that given above, and can be treated as a system consisting of two single-phase circuits.

The wiring of a three-phase system is as shown in Figs. 16a and 16b, the former being known as the "Y" system or "Star" system, and the latter as the "Delta" (Δ) system or "Mesh" system. When the Y system is required for both lighting and power, it is arranged as shown in Fig. 16c.

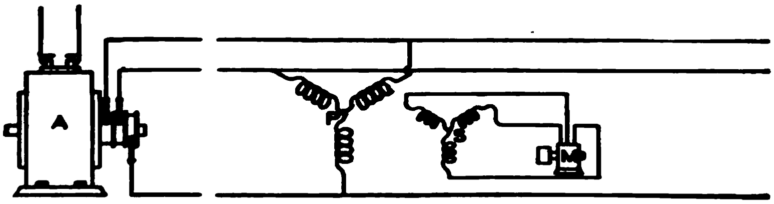


Fig. 16a.

The Direction of Rotation of the various machines is sometimes a matter of doubt or trouble. Almost any generator or motor is intended to be run in a certain direction; that is, it is called "right-handed" or "left-handed" according to whether the armature does or does not revolve like the hands of a clock, when looked at from the pulley end. Generators and motors are usually esigned to be right-handed, but the manufacturer will make them ft-handed if specially ordered. This may be required because he other pulley to which the machine is to be connected happens o revolve left-handed; or it may be necessary in order to bring ne loose side of the belt on top, or to permit the machine to sition where space is limited.

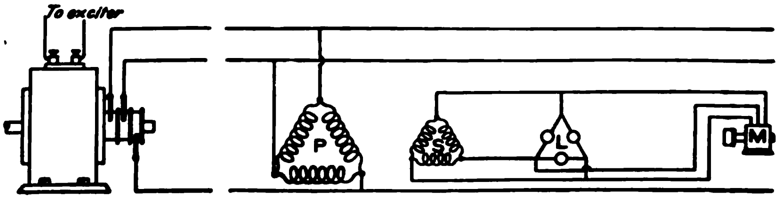


Fig. 16b.

To reverse the direction of rotation of an ordinary shunt (or series) direct-current bipolar motor, the brushes may simply be reversed as indicated in Fig. 17, without changing any connection. This changes the point of contact of each brush tip 180°.

If the machine is multipolar, a similar change must be made, amounting to 90° in a four-pole, 45° in an eight-pole machine, etc.

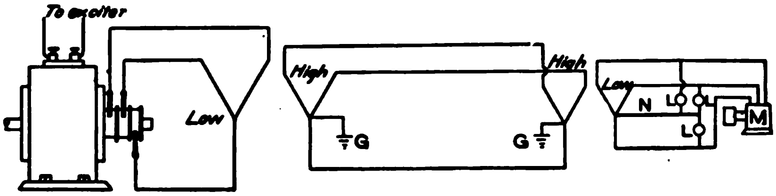


Fig. 16c

The direction of the current and the polarity of the field magnets remain the same as before; all that is changed is the direction of rotation and the position of the brushes. This applies to any machine (either motor or gnerator) except arc dynamos and one or two other peculiar machines, which require to be run in a certain direction to suit the regulating apparatus.

A separately excited alternating-current generator can be reversed in direction of rotation without changing any connection. A self-exciting or compound-wound alternator requires the brushes that supply the direct current to the field to be reversed upon the commutator, and their tips moved through an angle as above stated, if the rotation is to be reversed.

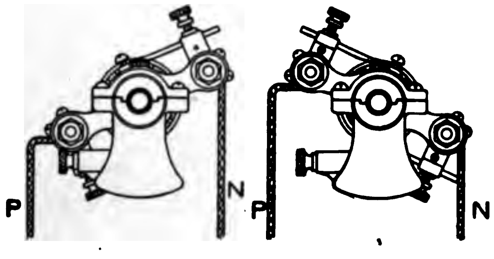


Fig. 17.

In any case, copper brushes (unless they be gauze brushes pressing radially upon the commutator) should point in the direction of rotation; but carbon brushes, particularly if they are perpendicular to the surface of the commutator, allow the armature to be revolved in either direction.

If the direction of the current from a generator is opposite to that desired, the two wires leading from it should exchange places in the terminals. If this is not desirable, the residual magnetism may be reversed by passing through the field winding a current opposite in direction to the original current.

Changing the direction of the current by reversing the main wires or otherwise, does not reverse the direction of rotation of any motor, since it reverses *both* the armature and the field. The way to reverse the direction of rotation is to reverse *either* the armature or the field connection *alone*, leaving the other the same as before.

Examination before Starting. The machine should be cleaned throughout, especially the commutator, brushes, electrical connections, etc. Any metal dust on the commutator or near electrical connections should be removed, as it is very likely to cause short circuits or grounds. Examine the machine carefully, and make sure that there are no screws or other parts that are loose or out of place. See that the oil-cups have a sufficient supply of oil, that the passages for the oil are clean, and that the feed is at the proper rate. In the case of self-oiling bearings, the rings or other means for carrying oil should work freely. See that the belt, if used, is in place, and that it has the proper tension. If the machine is being started for the first time, it should be turned a few times by hand, or run very slowly, in order to determine whether the shaft revolves easily and the belt runs on centers of pulleys.

The brushes should be carefully examined, and adjusted to make good contact with the commutator at the proper point, the switches connecting the machine to the circuit being left open. The machine should then be started with care, and brought up to full speed gradually, if possible. The person who starts either a dynamo or a motor should closely watch the machine and everything connected with it, and should be ready to throw it out of circuit and stop it instantly if the least thing seems to be wrong. He should then be sure to find out and correct the trouble before starting.

Generator. A generator is usually brought up to speed either by starting its engine or other prime mover, or by connecting it to a source of power already in motion, The former should be attempted only by a person competent to manage steam engines or the prime mover in question. The mere mechanical connecting of a generator to a source of power is usually not difficult; but it should be done carefully and intelligently, even if it only requires throwing in a friction-clutch or shifting a belt from an idle pulley. To put a belt on a pulley in motion is difficult and dangerous, particularly if the belt is large or the speed is high; and should not be tried except by one who knows just how to do it. Even if a stick is used for this purpose, it is apt to be caught and thrown around by the machinery unless used in exactly the right way.

In many cases generators are brought to full speed before the brushes are put in contact with the commutator; but this is not necessary. If the brushes are in contact before starting, they can be more easily and perfectly adjusted, and the E. M. F. will come up slowly, so that any fault or difficulty will develop gradually and can be corrected, or the machine stopped, before any injury is done. In fact, if the machine is working alone on a system, and is absolutely free from any danger of short-circuiting any other machine or storage battery on the same circuit, it may be started while connected to the circuit, but not otherwise (see next article). With a large number of lamps connected to the circuit, the field magnetism and voltage might not be able to "build up" until the line is disconnected.

If one generator is to be connected to another or to a circuit having other generators or a storage battery working upon it, the greatest care should be taken. This coupling together of generators can be done perfectly, however, if the correct method is followed, but is likely to cause serious trouble if any mistake is made.

Two or more machines are often connected to a common circuit. This is especially the case in central stations where the load varies so much that, while one generator may be sufficient for certain hours, two, three, or more machines may be required at other times. The various ways in which this is done depend upon the character of the machines and of the circuit.

Generators may be connected together either in parallel or in series.

Generators in Parallel. In this case the + (positive or plus) terminals are connected together or to the same line, and the − (negative or minus) terminals are connected together or to the other line. The currents (*i. e.*, amperes) of the machines are thereby added, but the E. M. F. (volts) is not increased. The chief condition for the running of generators in parallel is that their voltages shall be equal, but their current capacities may be different.

For example: A generator producing 10 amperes may be connected to another generating 100 amperes, provided the voltages agree. Parallel working is therefore suited to constant-potential circuits. A generator to be connected in parallel with others or with a storage battery, must first be brought up to its proper speed, E. M. F., and other working conditions; otherwise it will short-circuit the system, and might burn out its armature. Hence it should not be connected to a circuit in parallel with others until its voltage has been tested and found to be equal to, or slightly (not over 1 or 2 per cent) greater than, that of the circuit. If the voltage of the dynamo is less than that of the circuit, the current will flow back through it and cause it to run as a motor. The direction of rotation is the same, however, if it is shunt-wound; and no great harm results from a slight difference of potential; but compound-wound machines require more careful handling.

Direct-Current Dynamos in Parallel are always Shunt-Wound (or Compound-Wound). The test for equal voltages may be made by first measuring the E. M. F. of the circuit and then of the machine by one voltmeter; or two voltmeters, one connected to each, may be compared (Fig. 18); or a differential voltmeter may be used. Another method is to connect the dynamo to the circuit through a high resistance and a galvanometer; and when the latter indicates no current, it shows that the voltage of the dynamo is equal to that of the circuit. A rougher and simpler way to do this is to raise the voltage of the dynamo until its "pilot-lamp," or other lamp fed by it, is fully as bright as the lamps on the circuit, and then to connect the dynamo to the circuit. Of course the lamps compared should be intended for the same voltage and in normal condition. Be sure to connect the positive terminal of the dynamo to the positive conductor, and the negative terminal to the negative conductor (Fig. 18); otherwise there will be a very bad short circuit.

When the dynamo is first connected in this way, it should supply only a small amount of current to the circuit (as indicated by its ammeter), and its voltage should then be gradually raised until it generates its proper share of the total current; otherwise it will cause a sudden jump in the brightness of the lamps on the circuit.

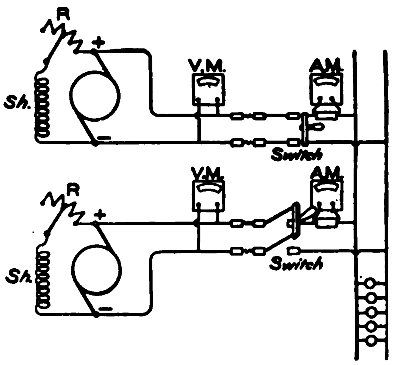


Fig. 18.

Series-Wound Dynamos in Parallel Not Used. If the machine is series-wound, the back current just described would cause a reversal of field magnetism and a very bad short circuit of double voltage. In fact, series dynamos in parallel are in unstable equilibrium, because if either tends to generate too little current, its own field, which is in series, is weakened, and thus still further reduces its current and probably will reverse the machine. This arrangement is therefore not used. One way in which this difficulty might be overcome is by causing each to excite the other's field magnet, so that if one generates too much current, it strengthens the field of the other and thus counteracts its own excess of power.

Another plan is to excite both fields by one machine, or, better, by both machines jointly, which is accomplished by connecting together the two + brushes and the two − brushes respectively, by the line and by what is called an **equalizer** (Fig. 19). In this way the electrical pressure at the terminals of the two armatures is made the same, and the currents in the two fields are also made equal. Series machines are not often run in parallel, but the principles just explained help the understanding of the next case, which is very important.

Compound Dynamos in Parallel. Since the field magnets of these machines are wound with series coils as well as with shunt coils, the coupling of them is a combination of the shunt and series cases just described.

The manner of connecting two or more compound dynamos to operate in parallel, is represented in Fig. 20, A being the armature, B the series, and C the shunt-field coils. R is the shunt-field rheostat; D and F are switches connecting the main terminals of the machine with the bus bars G and I, respectively; and E is a switch to connect the equalizer H with the brush end of the series coil B.

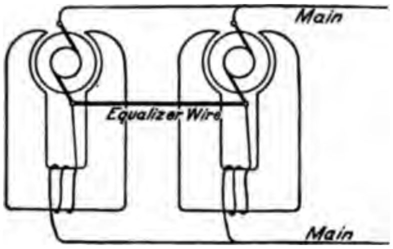


Fig. 19.

Assume that machine No. 1 is already in operation with its switches D, F, and E closed, and that it is desired to have machine No. 2 thrown in circuit. The procedure is as follows:

Bring machine No. 2 up to its rated speed, and adjust its pressure by means of the shunt-field rheostat until it is a little greater (about 1 per cent) than the difference of potential between the bars G and I. This fact may be ascertained by comparing two voltmeters connected to the dynamo and to the bus bars respectively; or by means of a single voltmeter connected through a double-throw switch, first to one and then to the other, which avoids the error due to a difference between two instruments. Another plan is to employ a differential voltmeter, that is, one having two windings on the movable coil, so that it indicates directly the difference in voltage between the two parts of the system.

After the pressure of the *incoming* dynamo has been properly regulated, the three switches E, F, and D are closed in the order named. If these points should be closed simultaneously by means of a triple-pole switch, a considerable current might flow through the series field winding, tending to increase still further the voltage of this dynamo, at the same time taking current away from the series coils of the other machines, and thereby reducing their potential. The shifting of the load thus produced might be so sudden and so great as to be objectionable. This action, however, is not of sufficient importance to overbalance the many advantages afforded by the use of a switch in which the three are combined as a triple-pole switch, thus guarding against the possibility of any accident due to closing the wrong circuit first.

After the machines have been thrown in parallel, their voltages should be adjusted by the shunt-field rheostats so that the load is properly divided between them.

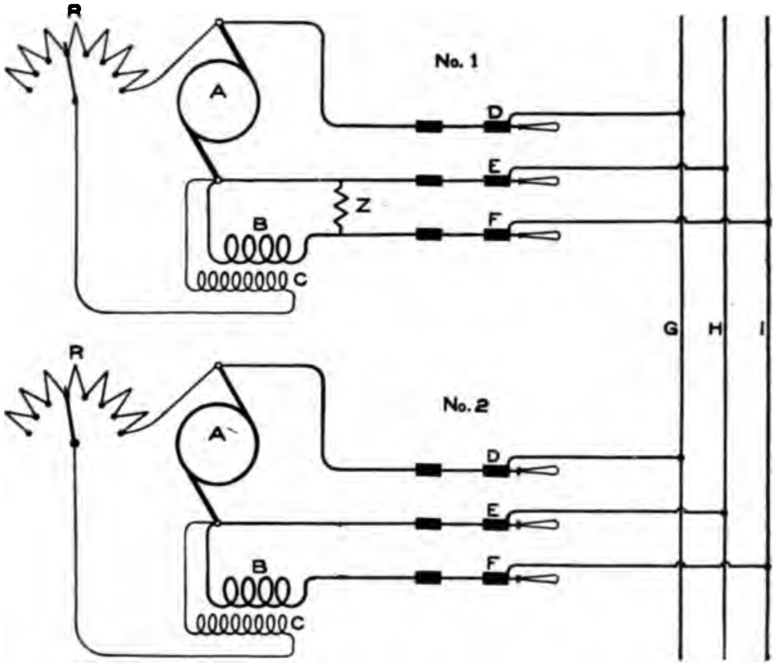


Fig. 20.

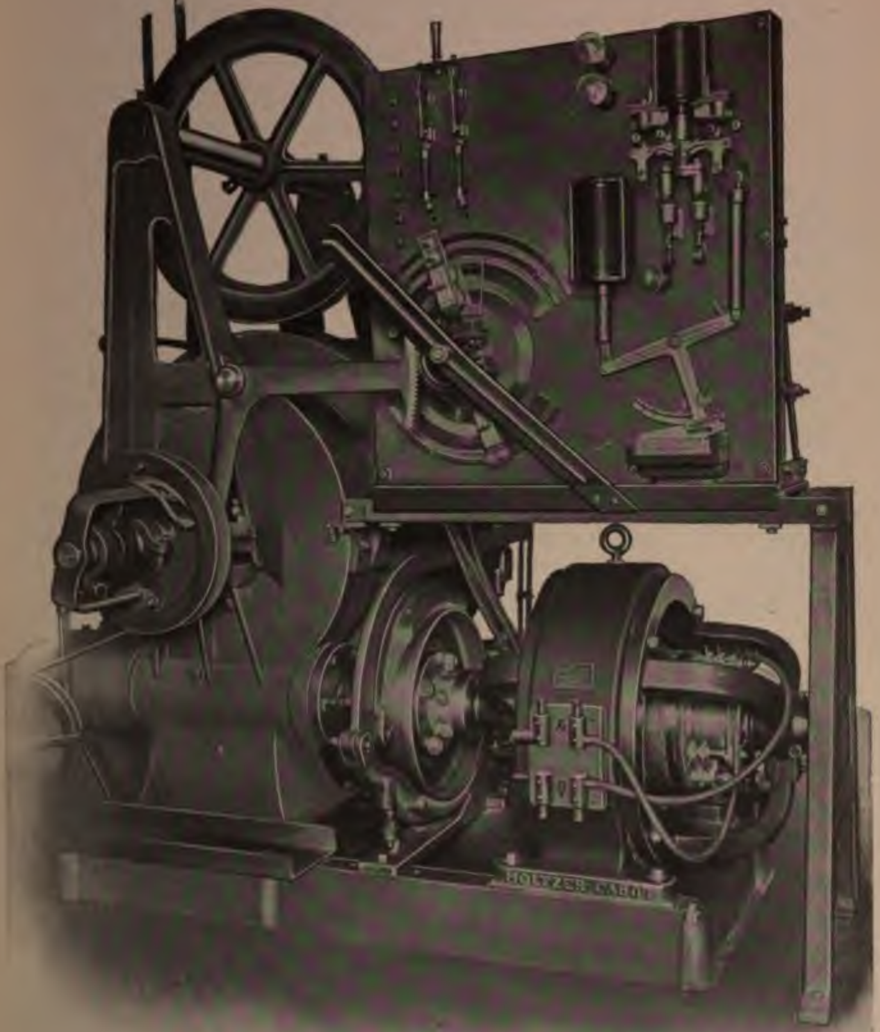
Compound dynamos of different size or current capacity may also be coupled as described, provided, of course, their voltages are equal; and provided also that the resistances of the series field coils, together with their leads to the bus bar, are inversely proportional to the current capacities of the several machines; that is, if a dynamo produces twice as much current, its series coil and lead should have half the resistance. It is further necessary that the two machines should agree in their action, so that a given increase in load will produce the same effect upon their voltages.

If they are not in agreement, they may be adjusted by slightly increasing the resistance of the series coil of that machine which tends to take too large a share of the load. This may be done by simply interposing a few extra feet of conductor of the same current capacity as the series coil, between the latter and the main conductor or bus bar. The shunts which are almost always used to adjust the effect of the series coils in compound dynamos (shown at Z in machine No. 1, Fig. 20), operate properly in the case of machines working *singly*, but are worthless for machines in parallel. The *resistances of the series coils themselves* must be adjusted as explained above, when two or more compound machines are run in parallel. The use of iron for this shunt makes the compounding effect in the dynamo more uniform, because its resistance, rising as the current through it increases, throws a greater fraction of the current through the series coils at full load, and compensates for the fact that the field magnetism, and consequently the voltage, does not increase proportionately with the increasing load current.

Shunt-wound dynamos run in parallel tend to steady each other, for, if one happens to run too fast, it has to do more work, which opposes the increase of speed; and it also takes part of the load off the other machines, which makes them run faster, thus producing equality. This mutual regulation will take care of any slight difference between machines, such as that caused by the slip of the belt, or even small differences in the governing action of the different engines that may be driving them. Compound-wound dynamos have very much less mutual regulation, owing to the effect of the series coil; and it is necessary that their speeds, voltages, etc., should regulate much more exactly than with simple shunt machines. They often work badly together owing to carelessness or to imperfect agreement between them, but with proper care and good apparatus they run well in parallel.

If generators are located at considerable distances from the switchboard, the equalizing connection may be run directly from one machine to the other with the equalizing switch (E, Fig. 20) on the frame of each, instead of running to the switchboard. This saves copper, especially in the case of large generators.

Alternators in Parallel. To run two alternators in parallel,



MOTOR DIRECT-CONNECTED TO ELEVATOR.

Holtzer-Cabot Electric Company.

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ASTOR, LENOX
TILDEN FOUNDATIONS

several conditions have to be fulfilled: The incoming machine—as in the sea of direct-current machines—must be brought up to nearly the same voltage as the first one; it must operate at exactly the same frequency; and, at the moment of switching in parallel, it must be in phase with the first machine. This correspondence of frequency and phase is called **synchronism.**

It is impossible with mechanical speed-measuring instruments to determine the speed as accurately as is necessary for this purpose. There is however, a very simple method of electrically determining small differences in speed or frequency. In Fig. 21, let M and N represent two single-phase alternators, which can be connected by means of the single-pole switch AB. Across the terminals of the switch is connected an incandescent lamp L, capable of standing twice the voltage of either machine. When AB is open, the circuit between the machines is completed through L. The two machines may be connected in parallel as follows: Assuming machine M already in operation, bring up machine N to approximately the proper speed, and voltage; then watch lamp L. If machine N is running a very little slower or faster than machine M, the lamp L will glow for one moment and be dark the next. At the instant when the voltages are equal in pressure and phase, L will remain dark; but when the phases are displaced by half a period, the lamp will glow at its maximum brilliancy. Since the flickering of the lamp is dependent upon the difference in frequency, the machines should not be thrown in parallel while this flickering exists. The prime mover of the incoming machine must be brought to the proper speed; and the nearer machine N approaches snychronism, the slower the flickering. When it is very slow, we can use the moment the lamp is dark to throw the machines in parallel by closing the switch across AB. The machines are then in phase, and tend to remain so, since if one slows down the other will drive it as a motor. It is better to close the switch when the machines are approaching synchronism than when they are receding from it, that is, at the instant the lamp becomes dark.

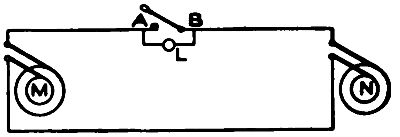


Fig. 21

This method of synchronizing is open to the following objections:

(*a*) The lamps may be dark with considerable difference in voltage. For instance, a 110-volt lamp is dark with a pressure of 20 to 25 volts.

(*b*) The lamp may be dark owing to a broken filament.

It may thus happen, with this arrangement, that the machines are placed in parallel while there is a considerable difference of voltage or phase existing, and an excessive rush of current will result.

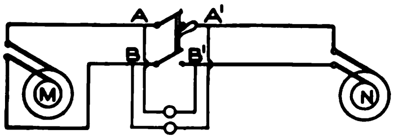


Fig. 22.

A method not open to the above objections is shown in Fig. 22. The machines to be switched in parallel are each connected to the bus bars by means of double-pole switches. Two incandescent lamps, of the machine voltage, are cross-connected as shown. If the machines are in phase and the voltages generated are equal in value, the difference of potential between A and a given point is the same as that between A' and the same point; likewise B and B' have the same relative potential values. Hence a lamp connected between A and B' would burn with the same brilliancy as if it were connected directly across AB; likewise with the other lamp. If, however, the machines happen to be directly opposite in phase but to be generating voltage of the same value, A and B' are of the same relative potential value, and B and A' are likewise of the same value; hence lamps cross-connected as in Fig. 22 would be dark. At any other phase difference the lamps will glow, but not so brightly as when in phase. Hence, with this arrangement, the machines should be thrown in parallel when the lamps are on the verge of maximum brightness, a condition readily determined, but not possible with the first method.

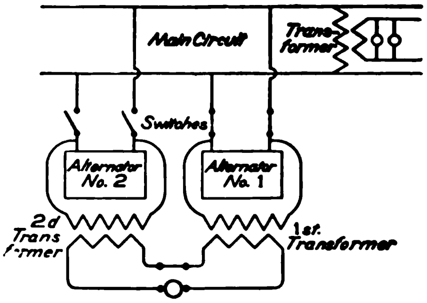


Fig. 23.

The connections as shown in Figs. 21 and 22 are not directly applicable to high-tension working, but require the introduction of transformers as shown in Fig. 23, which is a modification of Fig. 22. The secondaries (of, say, 50 volts each) should be connected in series with each other and to one 100-volt lamp. When the two machines are opposed in phase, the lamp is dim. If the lamp flickers badly, the phase is not right; but if the lamp is steady at full brightness, the machines are in phase, and they may be connected without disturbing the circuit, by closing the main switch.

If alternators are rigidly connected to each other or to the engine, so that they necessarily run exactly together, there is no need of bringing them into step each time, but they should be adjusted to the same phase in the first place.

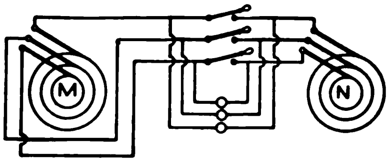


Fig. 24.

The connections of the synchronizing lamps of a three-phase system are similar to those for a single-phase system. For instance, the method employed in Fig. 21 may be extended, and lamps connected as in Fig. 24. If the three lamps simultaneously become dark or bright, the connections are correct, and the three switches may be closed at an instant of darkness. It may happen, however, that the lamps do not become bright or dark simultaneously but successively This indicates that the order of connection of the leads of one machine does not correspond with that of the other. In this case, transpose the leads of one machine until the proper or simultaneous action of the lamps is obtained. After the machines have been properly connected, it is sufficient to synchronize with one of the lamps. Similarly, with high-tension sytsems, only a single-phase transformer is required, connected as shown in Fig. 25.

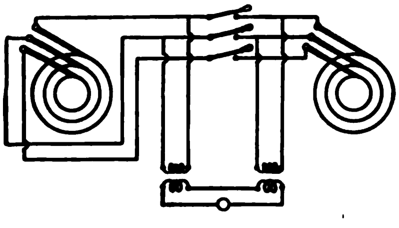


Fig. 25.

Generators in Series. This arrangement is less common than parallel working, and does not usually operate so well, except with series-wound machines on arc circuits, which is v successful. The conditions are exactly opposite to those in the preceding group—generators in parallel.

To connect machines in series, the positive terminal of one must of course be connected to the negative terminal of the next, and so on. Each must have a current capacity equal to the maximum current on the circuit, but they may differ to any extent in E. M. F. The voltages of machines in series are added together; and therefore danger to persons, insulation, etc., is increased in proportion.

Series-Wound Direct-Current Dynamos in Series are connected in the simple way represented in Fig. 26; but, usually machines connected in series are for arc lighting—for example, when two dynamos, each of 40 lights capacity, are run on one circuit of 80 lamps, in which case the dynamos usually have some form of regulator. These regulators do not usually work well together, because they are apt to "seesaw" with each other. This difficulty may be overcome either by connecting the regulators so that they work together, or by setting one regulator to give full E. M. F. and letting the other alone control the current. This latter plan can be followed only when the variation in load does not exceed the power of one machine. Constant-current dynamos having regulators with little inertia in the moving parts, and thus little tendency to "overshoot," such as the Brush machine, can be run in series without much trouble.

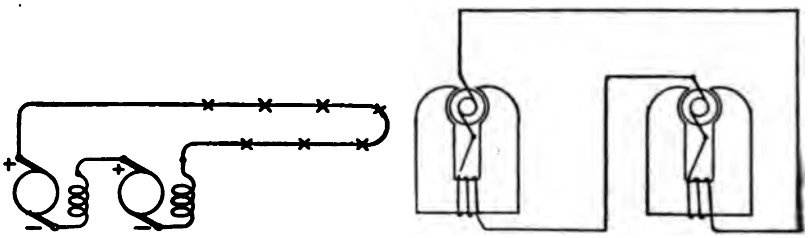


Fig. 26.

Shunt or Compound Dynamos in Series run well, provided the shunt-field coils are connected together to form one shunt across both machines. If the machines are compound, all of the series coils must be connected in series with the main circuit. Another plan is to connect each shunt field so that it is fed only by the armature of the other machine ; or both the shunt coils may be connected so as to be fed by one armature, the series coils being in the main circuit as before.

Alternators in Series. The synchronizing tendency which makes it possible to run alternators in parallel, causes them to get out of step and become opposed to each other when it is attempted to run them in series. It is therefore impracticable to run them in series unless their shafts are rigidly connected so that they must run exactly in phase and thus add their waves of current instead of counteracting each other. This case rarely occurs.

Dynamos on the Three-Wire System (Direct-Current). In the ordinary three-wire system for incandescent lighting and power service, no particular precautions are required in starting or connecting the machines; and either of the two arrangements shown in Figs. 27*a* and 27*b* may be adopted. The two sides of the system are almost independent of each other, and form practically separate circuits, for which the middle or neutral wire acts as a common conductor. There is, however, a tendency for the dynamos (Fig. 27*a*) to be reversed in starting up, in shutting down, or in the case of a severe short circuit. This can be avoided by exciting the field coils of all the dynamos from one side of the system, or from a separate source. To obtain good regulation, it is necessary to balance the load equally on both sides of the system. It is advisable to employ 220-volt motors on 110-volt 3-wire systems, and to connect them across the outside conductors so that the motor load shall not unbalance the system.

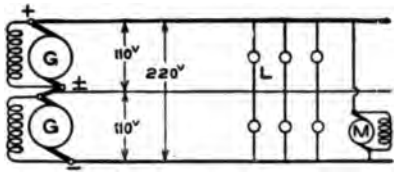


Fig. 27*a*.

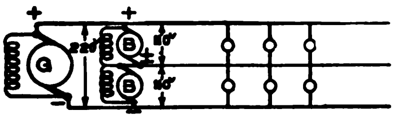


Fig. 27*b*.

KINDS OF MOTORS, CONNECTIONS, AND STARTING.

The general instructions relating to the adjustment of brushes, screws, belt, oil-cups, etc., given in relation to the generator, should be carefully followed preparatory to starting a motor. Th starting of a motor is usually a simple matter, since it consists merely in operating a switch; but in each case there are one or more important points to be considered

CONSTANT-POTENTIAL D. C. CIRCUITS.

Shunt-Wound Motor. A motor to operate at nearly constant speed, with varying loads, on a D. C. constant-potential system (110- or 220-volt lighting circuits) is usually plain shunt-wound. This is the commonest form of stationary motor. The field coils are wound with wire of such a size as to have the proper resistance and resulting magnetizing current; and since the potential applied is practically constant, the field strength is constant.

In starting shunt motors, no trouble is likely to occur in connecting the field to the circuit. The difficulty is with the armature current, because the resistance of the armature is very low in order to get higher efficiency and constancy of speed, and the rush of current through it in starting might be twenty or more times the normal number of amperes. To avoid this excessive current, motors are started on constant-potential circuits through a rheostat or "starting-box" containing resistance coils.

The main wires are connected through a branch cut-out (with safety fuses), and preferably also a double-pole knife switch Q, to the motor and box, as indicated in Fig. 28. When the switch Q is closed, the arm S being in its left-hand position, the field circuit is closed through the contact stud *f*, and the armature circuit is closed through the resistance coils *a*, *a*, *a*, which prevent the rush of current referred to. The motor then starts, and as the speed rises it generates a counter E. M. F., so that the arm S can be turned as shown until all the resistance-coils *a*, *a*, *a*, are cut out, and the motor is directly connected to the circuit and running at full speed. The arm S should be turned slowly enough to allow the speed and counter E. M. F. to come up as the resistances *a*, *a*, *a* are cut out. The arm S should positively close the field circuit first, so that the magnetism reaches its full strength (which may take several seconds) before the armature is connected.

In the arrangement shown in Fig. 28 the release magnet has its coils in series with the field. As long as the motor is in operation, the core is energized and the arm S is held in the position shown. If, however, the current supplied to the motor is cut off and the motor comes to rest, the core of the magnet loses its attractive force, and the arm S is released, being automatically moved back to the starting position by a spring.

The coils *a*, *a*, *a* are made of comparatively fine wire, which can carry the current only for a few seconds in a "starting-box;"

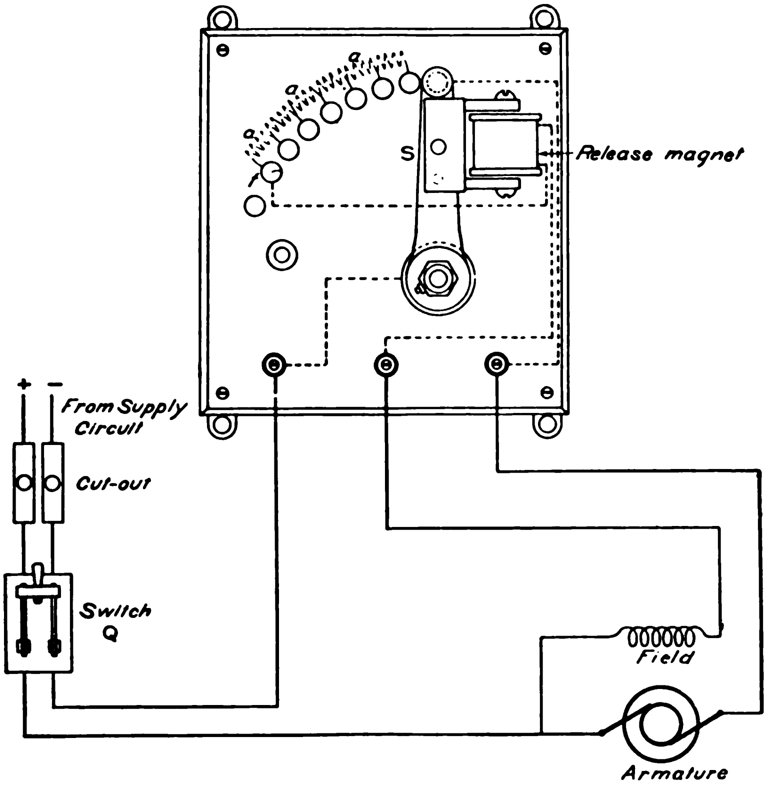


Fig. 28.

but if the wire is large enough to carry the full current continuously, it is called a "regulator," because the arm S may be left so that some of the resistances *a*, *a*, *a* remain in circuit, and they will have the effect of reducing the speed of the motor, which is often very desirable.

In some cases where a circuit is used exclusively for a si
motor, the speed is regulated without heavy resistances b

the E. M. F. of the dynamo which supplies the circuit. The dynamo regulator is then placed near the motor. The advantage is that the regulator is not compelled to control a heavy current, but a special circuit of unvaried pressure must be provided to keep the field of the motor constant.

The speed control of a shunt motor may be simply obtained as follows:

a. For lower speeds, insert resistance in series with the armature circuit. The resulting I. R. drop reduces the value of the voltage applied to the armature terminals, and thus reduces the speed.

b. For higher speeds, insert resistance in the shunt-field circuit. This reduces the magnetic flux, and to generate the same C. E. M. F. the motor must speed up.

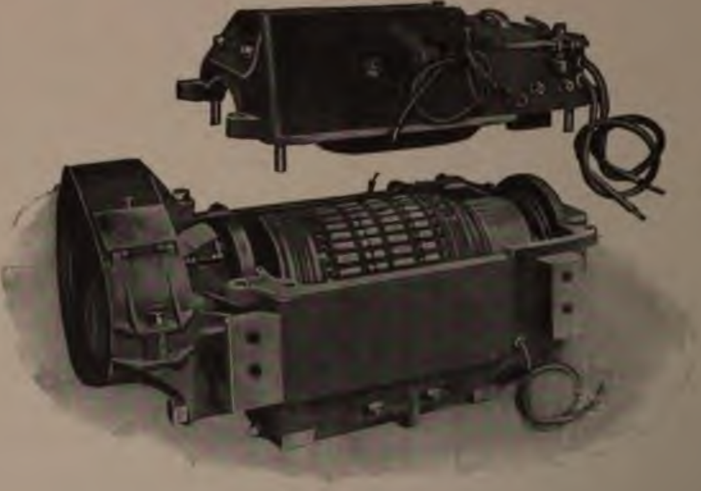


Fig. 29.

The field circuit of a shunt motor should never be opened while pressure is still applied to the armature terminals, as under these conditions the armature current becomes very excessive and the armature is likely to race and probably be damaged. A moderate decrease in field strength only is allowable; otherwise sparking becomes excessive.

Series-Wound Motor. The ordinary electric railway motor on the 550-volt trolley system is the chief example of the class (Fig. 29.) Motors for fans, pumps, or electric elevators and hoists are either of this kind or of the compound type. A rush of current tends to occur when the series type of motor is started, similar to that in the case just described; but it is less, because the field-coils are in series, so that their resistance and self induction reduce the excess. Furthermore, the counter E. M. F. is greater even at low speed because the heavy current produces a strong field.

The connections as indicated in Fig. 30 are very simple, the armature, field-coils, and rheostat all being in series and carrying the same current.

The series-wound motor on a constant-potential circuit does not have a constant field strength, and does not tend to run at constant speed, like a shunt motor. In fact it may "race" and tear itself apart if the load is taken off entirely; it is therefore suited only to railway, pump, fan, or other work where variable speed is desired, or where there is no danger of the load being removed or a belt slipping off. It is also used where the potential is subject to sudden and large drops, as on the ends of long trolley circuits, because in such a case a shunt motor becomes momentarily a generator and sparks very badly. The fields of series motors are sometimes "overwound," that is, so wound that they will have their full strength with even one-half or one-third of the normal current. The objects are to secure a nearly constant speed with varying loads, to enable the motor to run at high efficiency when drawing small currents, and to prevent sparking at heavy loads.

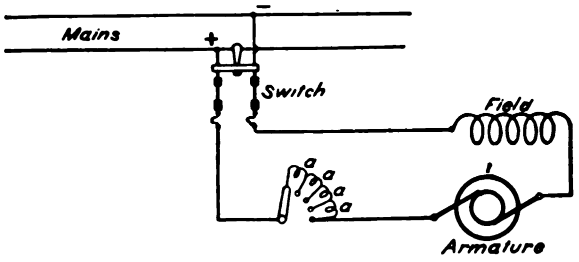
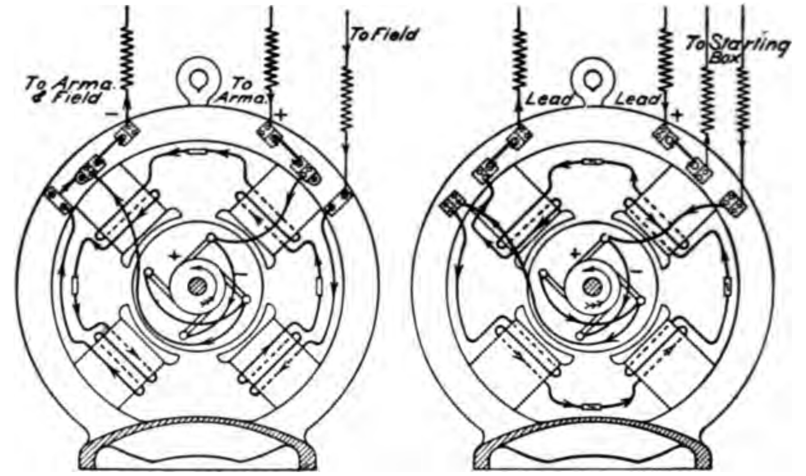


Fig. 30.

In multipolar motors having more than two field-coils, the coils are all connected together, and are equivalent to the si pairs of coils shown in the several diagrams. Being s however, it is sometimes necessary to trace out the connections. Fig. 31 represents the necessary connections for a four-pole motor, shunt-wound and series-wound.

Differentially-Wound Motor. This is a shunt-wound motor with the addition of a coil of large wire, on the field, connected in series with the armature in such a way as to oppose the magnetizing effect of the shunt winding and weaken the field, thus causing the motor to speed up when the load is increased, as an offset to the slowing-down effect of load.

It was formerly used, for obtaining very constant speed, but it has been found that a plain shunt motor is sufficiently constant for almost all cases. The differential motor, if overloaded, has the great disadvantage that the current in the opposing (series) field-coil becomes so great as to kill the field magnetism; and instead of increasing or keeping up its speed, the armature slows down or stops, and is likely to burn out; whereas a plain shunt motor can increase its power greatly for a minute or so when overloaded, and will probably throw off the belt or carry the load until the latter decreases to the normal amount.



Shunt-wound Motor. Series-wound Motor.

Fig. 31.

Compound-Wound Motor. This type of motor is also provided with a shunt and a series-field winding, Fig. 32, but in this instance they magnetize the field in the same direction, or, in other

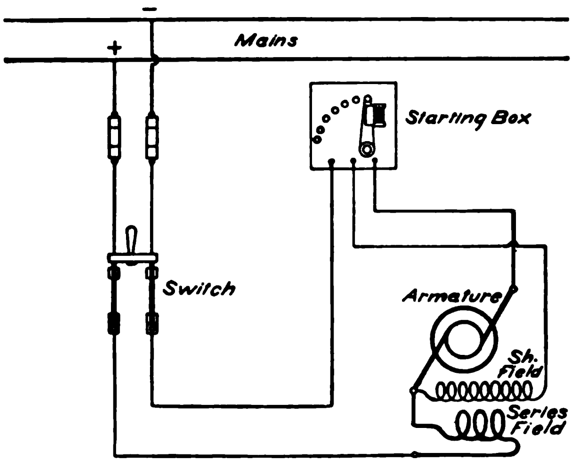


Fig. 32.

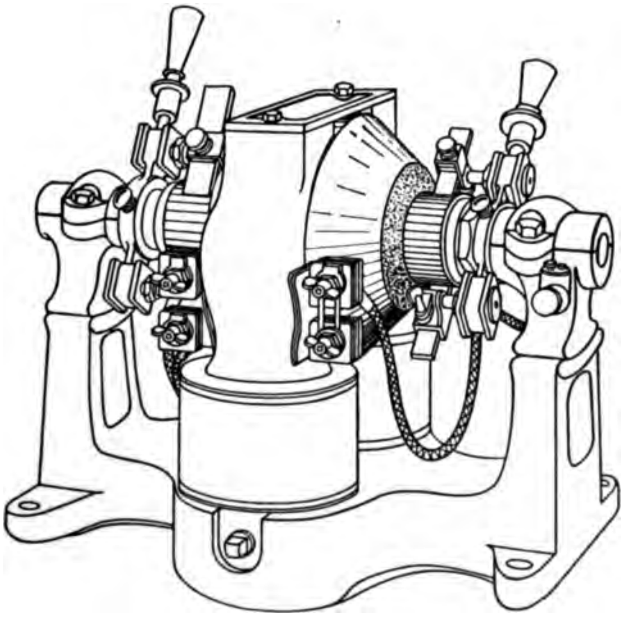


Fig. 33.

[illegible]

[illegible] laminated [illegible] are as follows:

[illegible] power factor, due to the na- [illegible] necessary on account of arma- [illegible]

[illegible] especially at starting and with [illegible] the fact that each armature coil is in turn short-circuited [illegible] it becomes the seat of very large induced currents, these reacting with the magnets and causing great heating and sparking.

Many attempts have been made to adapt this motor for general use, as it possesses the valuable features of great starting torque and convenient speed control; but, on account of the high frequencies heretofore employed, they have not been successful. Recently, however, the Westinghouse Electrical Manufacturing Company have been experimenting with a low frequency (16⅔ to 25 cycles), and under these conditions the motor gives promise of success.

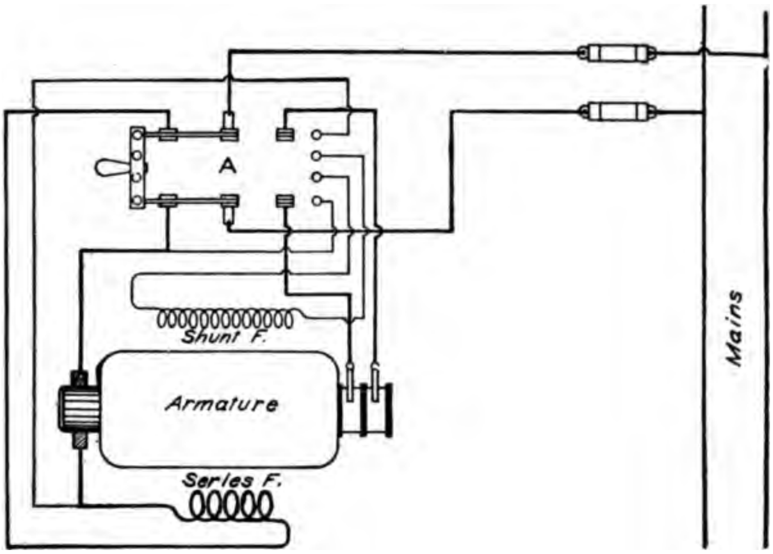


Fig. 34.

An ordinary single-phase alternator can be used as a motor; but it must first be brought up to synchronism with the supply generator by means of some auxiliary starting device (steam engine, polyphase induction motor, etc.) before the load can be applied. In this form the machine is known as the *single-phase synchronous motor.* The condition of synchronism is determined by one of the methods described in the paragraph on "Alternators in Parallel." After the motor is in synchronism it may be connected to the circuit by closing its supply switch; and it will then continue to run at an absolutely constant speed, unless heavily overloaded, when it falls out of step and stops.

On account of these features, the synchronous motor is not to be recommended for general application. Various manufacturers, notably the Wagner Electric Company, and the Fort Wayne Electric Company, manufacture self-starting, single-phase synchronous motors, usually limited, however, to the smaller sizes. The construction and action of the Fort Wayne motor (Fig. 34), which is a combination of the two preceding types, are as follows: The armature core is provided with a double winding, one equipped with collecting rings, and the other with an ordinary commutator. The field magnet, which is laminated, is wound with two separate circuits, one being of low resistance and a small number of turns, the other of high resistance and many turns, like an ordinary shunt-field winding. In starting, the motor runs as a series machine, the low-resistance field being in series with the commutated armature winding and the line. When it has reached synchronism, the switch A, on the top, is thrown over to the right, and the supply line connected with the collector rings and the corresponding armature winding; while the commutated end is connected to the other field winding, and thus provides the direct current necessary for field excitation.

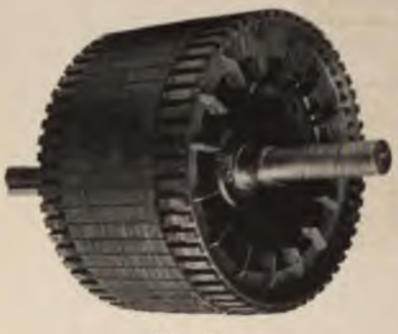


Fig. 35.

In addition to the single-phase there is also the *polyphase synchronous motor*. This latter form, however, is self-starting without field current, but will not carry a load until it is running in synchronism. When this condition is reached, the field circuit should be closed before applying the load.

A great advantage of the synchronous motor is that when its field is over-excited, it draws a leading current from the line, thus acting like a condenser and tending to neutralize the inductive effect of other machinery, so that the power factor of the whole system is raised. The most extensive use of the synchronous motor is as a part of the rotary converter, which is employed to convert alternating into direct currents, for traction and electro-chemical purposes.

The satisfactory use of alternating currents for power purposes depends mainly on the *polyphase induction motor*, as in this form the A. C. motor is self-starting with considerable torque and operates at a practically constant speed from no load to a heavy overload. Induction motors are designed for the standard voltages and frequencies.

In most induction motors now built, the primary, or part into which the currents from the line are led, is the stationary member, or *stator*. The secondary, in which the induced currents are set up, is the rotating member, or *rotor*. There are two kinds of rotor windings, the simpler being that known as the "squirrel-cage." This winding is made up of a number of copper bars, equally spaced around the rotor core, and imbedded therein. The terminals of these inductors are interconnected, or short-circuited, by means of heavy copper rings placed at both ends of the core, as shown in Fig. 35.

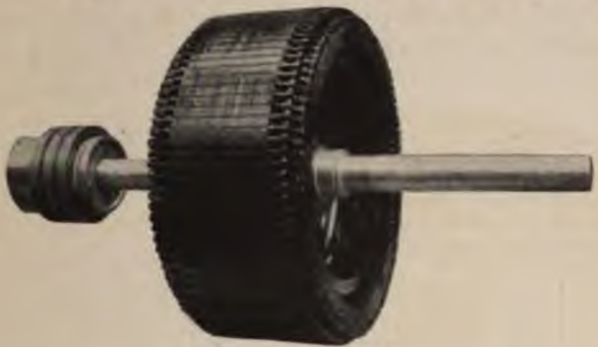


Fig. 36.

The other form of winding is of the drum species, usually three-phase, Y-connected; and the coils are located at 120° intervals (the arc between centers of adjacent poles being called 180°) with respect to each other. The free ends of the windings are respectively brought out to three slip or collecting rings ; and on this account this type of rotor is frequently called the "slip-ring" rotor (Fig. 36).

Starting Induction Motors. In small sizes, up to 3 or 5 H. P., the induction motor can be started by connecting its stator terminals directly to the line. But with larger sizes the inrush of current is excessive and likely to disturb the system; accordingly some form of starting device is usually necessary.*

Starting Compensators. This inrush of current can be avoided by inserting a starting resistance, or inductance, in series with the primary winding and the line, or by using some other means of cutting down the applied E. M. F. The torque of an induction motor decreases as the square of the applied voltage, so that this method of starting results in a greatly reduced starting effort. However, in many instances, motors are not started up under full load, so that this may not be a serious objection.

While a resistance could be employed as described, it is more economical to employ an auto-transformer (that is, a transformer having but one coil, which serves as both a primary and a secondary), or *compensator*, as it is called when used for this purpose Compensator connections for a three-phase motor are represented in Fig. 37. The compensator consists of coils *a*, *b*, and *c*, wound on a laminated-iron core, each coil being provided with a number of taps, 1, 2, 3, etc. The pressure applied to the motor at starting is proportioned to the amount of each coil included in the circuit. While the compensator winding is provided with taps, only that one which is most suitable for the work is used after the equipment is permanently installed. When the switch is in the

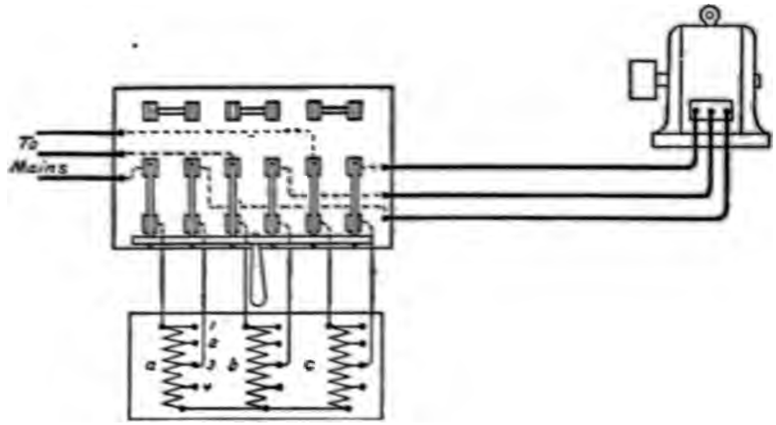


Fig. 37.

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* This inrush of current is frequently three times the rated load current

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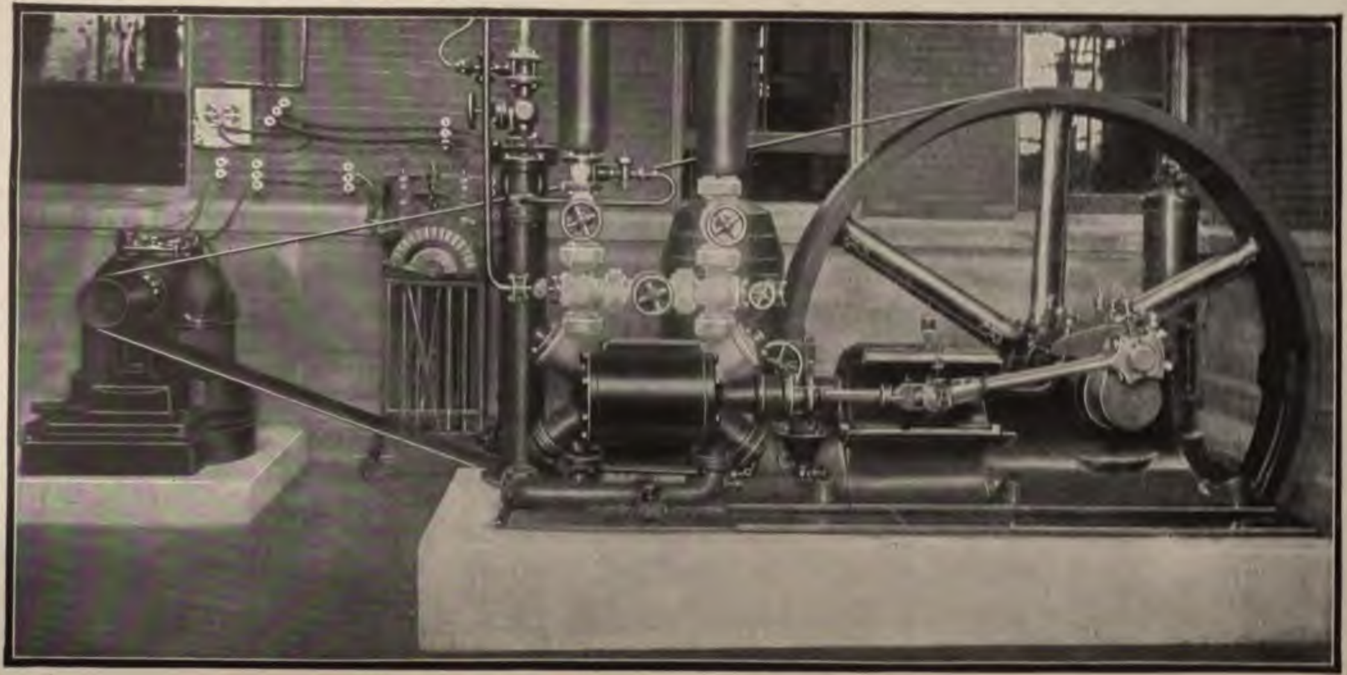
ASTOR, LENOX
TILDEN FOUNDATIONS



12-TON LINDE REFRIGERATING MACHINE.

Operated by an Electric Motor.

Fred W. Wolf Company

lower position as indicated, a part of each coil is in series with each leg of the system leading to the motor; and the applied voltage is correspondingly cut down. After the motor reaches its rated speed, the switch is thrown to the upper or running position, and the stator or primary terminals are connected directly to the line. The compensator thus prevents an excessive inrush of current, and gives the motor a smooth start, although it decreases the starting torque, compared with that due to full line pressure.

Speed Regulation of Induction Motors. For some classes of work, it is desirable to have induction motors arranged so that their speed can be controlled, the usual methods being:

a. The insertion of a variable resistance in the rotor circuit.

b. Cutting down the voltage applied to the stator, as just described.

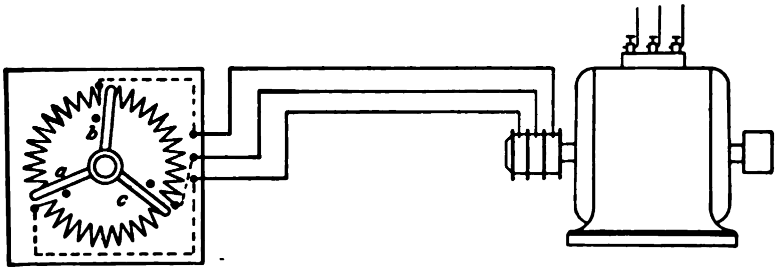


Fig. 38.

The more satisfactory method of speed control, is that with variable resistance inserted in the rotor circuit, the power-factor and hence the efficiency of the system being greater at reduced speeds than with the compensator or equivalent device. It requires, however, the use of collector rings, connecting brushes, and leads, since a resistance for continuous service is too bulky to be placed within the machine. Still further, the heat developed in the resistance would heat the machine too much. The controller itself looks like an ordinary trolley car controller, but for simplicity it is represented as a three-armed controller (Fig. 38) in which the arms *a*, *b*, and *c* are in electrical contact under the handle. The resistance is provided in three sets, one for each free end of the rotor winding; and each set is subdivided so that it can be gradually cut out of circuit as the motor speed increases. Frequently the controller is so arranged that the first motion of the handle closes the supply lines, and subsequent motions vary the resistances in the rotor circuit, thus performing the function of a supply switch and speed controller.

Another method of speed control, is to have the winding on the stator arranged so that by means of a suitable controlling switch, the number of poles can be changed. This is a very economical method from the electrical standpoint, and gives a very wide range of control, but, on account of its complexity and cost, is used only to a limited extent.

In general, the induction motor does not allow of the same range of speed control as does the direct-current motor, and the methods employed for this purpose are not efficient.

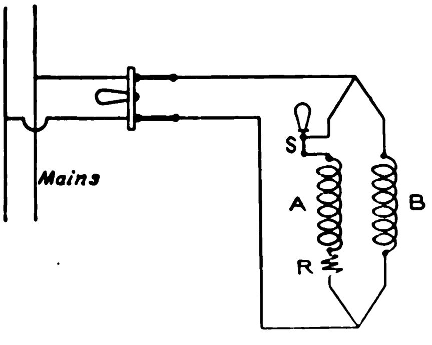


Fig. 39.

Single-Phase Induction Motor. A two or three-phase induction motor will operate fairly well, if, after reaching full speed, all but one of the phases be cut out. It will not however start from rest under the influence of single-phase excitation. Hence, to start an induction motor from the lines of a single-phase system, currents differing in phase must be obtained. This is accomplished by connecting the two primary windings A and B (in the case of a two-phase motor) in parallel to the single-phase mains, at the same time connecting in series with one winding a resistance R (Fig. 39). The currents flowing through these two windings will then differ in phase, one leading the other on account of a difference in their constants, and will thus produce a rotating field, and the motor will then start up.* When the motor has reached full speed, one phase may be cut out by opening the switch at S, and the machine will carry its load. The resistance R may be replaced to advantage by a condenser, especially on small machines. Such a machine is commonly called a "split-phase" motor.

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* This field is not a rotary field in the full sense, being elliptical in character.

DIRECTIONS FOR RUNNING GENERATORS AND MOTORS.

After any one of these machines has been properly started, it usually requires little attention while running; in fact, generators or motors frequently operate all day without any care whatever.

In the case of a machine that has not been run before or has been changed in any way, it is wise to watch it closely at first. It is also well to give the bearings of a new machine plenty of oil at first, but not enough to run on the armature, commutator, or any part that would be injured by it; and to run the belt (if used) rather slack until the bearings and belt are in easy working condition.

If possible, a new machine should be run without load or with a light one for an hour or two, or for several hours in case of a large machine; and it is bad practice to start a new machine with its full load or even a large fraction of it. This is true even if the machine has been fully tested by its manufacturer and is in perfect condition, because there may be some fault in setting it up or some other circumstance that would cause trouble. All machinery requires some adjustment and care for a certain time to get it into smooth working order.

When this condition is reached the only attention required is to supply oil when needed, keep the machine clean, and see that it is not overloaded. A generator requires that its voltage or current should be observed and regulated if it varies. The attendant should always be ready and sure to detect the beginning of any trouble, such as sparking, heating, noise, abnormally high or low speed, etc., before any injury is caused, and to overcome it. Such directions should be pretty thoroughly committed to memory in order promptly to detect and remedy any trouble when it occurs suddenly, as is usually the case. If possible, the machine should be shut down instantly when any indication of trouble appears, in order to avoid injury and give time for examination.

Keep all tools or pieces of iron or steel away from the machine while running, as they might be drawn in by the magnetism, perhaps getting between the armature and pole pieces and ruining the machine. For this reason use a zinc, brass, or copper oil-can instead of one of iron or "tin" (tinned iron)

Particular attention and care should be given to the commutator and brushes, to see that the former keeps perfectly smooth and that the latter are in proper adjustment. (See "Sparking.")

Never lift a brush while the machine is delivering current unless there are one or more other brushes on the same side to carry the current, as the spark might make a bad burnt spot on the commutator, or might burn the hand.

Touch the bearings and field coils occasionally to see whether or not they are hot. To determine whether the armature is running hot, place the hand in the current of air thrown out from it by centrifugal force.

Special care should be observed by any one who runs a generator or motor, to *avoid overloading* it, because this is the cause of most of the troubles which occur.

Personal Safety. Never allow the body to form part of a circuit. While handling a conductor, a second contact may be made accidentally through the feet, hands, knees, or other part of the body, in some peculiar and unexpected manner. For example, men have been killed because they touched a "live" wire while standing or sitting upon a conducting body.

Rubber gloves or rubber shoes, or both, should be used in handling circuits of over 500 volts.* The safest plan is not to touch any conductor while the current is on; and it should be remembered that the current may be present when not expected, owing to an accidental contact with some other wire or to a change of connections. Tools with insulated handles, or a dry stick of wood, should be used instead of the bare hand.

The rule to use *only one hand* when handling dangerous electrical conductors or apparatus is a very good one, because it avoids the chance, which is very great, of making contacts with both hands and getting the current through the body. This rule is often made still more definite by saying, "Keep one hand in your pocket," in order to make sure not to use it. The above precautions are often totally disregarded, particularly by those who have become careless through familiarity with dangerous currents. The result has been that *almost all persons accidentally killed*

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* These articles should be subjected to tests at frequent intervals, so as to determine their condition.

by artificial electricity have been experienced linemen or station men.

Stopping Generators or Motors. This is accomplished by following substantially the same directions as for starting them, but in the reverse order.

A generator operating alone on a circuit can be slowed down and stopped without touching the switches, brushes, etc., in which case the current gradually decreases to zero; and then the connections can be opened without sparking or any other difficulty.

However, when a generator is operating in parallel with others, or with a storage battery, it must not be stopped or reduced in speed, until it is entirely disconnected from the system, otherwise it will act as a short circuit. Furthermore, the current generated by it should be reduced nearly to zero before its switch is opened. This is accomplished by adjusting the field rheostat of the machine to be cut out, great care being taken that the change is gradual. If the reduction be rapid, the voltage of the machine may drop so low as to cause a back current to flow.

A **constant-current generator** may be cut into or out of circuit in series with others, and can be slowed down or stopped; or its armature or field coils may be short-circuited to prevent the action of the machine, without disconnecting it from the circuit. *It is absolutely necessary, however, to preserve the continuity of the circuit*, and not to attempt to open it at any point, as this would produce a dangerous arc. Hence a by-path must be provided by closing the main circuit around the generator, before disconnecting it. This same rule applies to any lamp, motor, or other device on a constant-current system.

Never, except in an emergency, should any circuit be opened when heavily loaded, for the reason that the flash at the contact points, discharge of magnetism, and mechanical shock which result, are decidedly objectionable.

A Constant-Potential Motor is stopped by turning the starting-box handle back to the position it had before starting (Fig. 28); or, *if there is a switch Q, connecting the motor to the circuit*, as there always should be, it should be opened, after which the starting-box handle is moved back to be ready for starting again.

Immediately after a machine is stopped, it should be thoroughly cleaned, and put in condition for the next run. When not in use, machines should, when feasible, be protected from dirt and moisture by covers of some waterproof material.

INSPECTING AND TESTING.

Adjustment and the other points which depend merely upon mchanical construction, are hardly capable of being investigated by a regular quantitative test, but they can and should be determined by thorough inspection. In fact a very-careful examination of all parts of a machine should always precede any test of it. This should be done for two reasons: first, to get the machine into proper condition for a fair test; and, second, to determine whether the materials and workmanship are of the best quality and satisfactory in every respect. A loose screw or connection might interfere with a good test; and a poorly fitting bearing, brush-holder, or other part might show that the machine was badly made.

If it is necessary to take the machine apart for cleaning or inspection, the greatest care should be exercised in marking, numbering, and placing the parts, in order to be sure to get them together exactly the same as before. In taking a machine apart or putting it together, only the minimum force should be used. Much force usually means that something wrong is being done. A wooden or rawhide mallet is preferable to an iron hammer, since it does not bruise or mar the parts. Usually screws, nuts, and other parts should be set up fairly tight, but not tight enough to run any risk of breaking or straining anything. Shaking or trying each screw or other part with a wrench or screw-driver, will show whether any of them are too loose or otherwise out of adjustment.

Friction. The friction of the bearings and brushes can be tested roughly by merely revolving the armature by hand, or slowly by power, and noting if it requires more than the normal amount of force. Excessive friction is quite easily distinguished, even by inexperienced persons. Another method is to revolve the armature by hand or otherwise, and see if it continues to revolve by itself freely for some time. A well-made machine in good condition and running at or near full speed, will continue to run for several minutes after the turning force is removed.

A method for actually measuring the friction consists in attaching a lever (a bar of wood, for example) to the shaft or pulley at right angles to it. The force required to overcome the friction and to turn the armature without current, is then determined by known weights or, more conveniently, by an ordinary spring balance. For convenience in dividing by the length of the lever, etc., to determine the value of the friction compared with the power of the machine, it should be exactly 1, 2, or 4 feet long. The friction of the bearings alone—that is, the pull which is required to turn the armature when the brushes are lifted off the commutator—should not exceed about 2 per cent of the total torque or turning force of the machine at full load. When the brushes are in contact with the commutator with the usual pressure, the friction should not then exceed about 3 per cent; that is, the brushes themselves should not consume more than 1 per cent of the total turning force.

Another method of measuring the friction of a machine is to run it by another machine used as a motor, and determine the volts and amperes required, first, with brushes lifted off, and second, with brushes on the commutator with the usual pressure. The torque or force exerted by the driving machine is afterwards measured by a Prony brake in the manner described hereafter for testing torque, care being taken to make the Prony brake measurements at exactly the same volts and amperes as were required in the friction tests. In this way the torques exerted by the driving machine to overcome friction in each of the first two tests are determined; and these torques, compared with the total torque of the machine being tested, should give percentages not exceeding those stated above for maximum values of friction. The magnetic pull of the field on the armature may be very great if the latter is not exactly in the center of the space between the pole pieces. This would have the effect of increasing the friction of the shaft in the bearings when the field is magnetized. It occurs to a certain extent in all cases, but it should be corrected if it becomes excessive. This may be tested by turning the current into the fields, being sure to leave the armature disconnected, and then turning the shaft with the lever as before. The friction in this case should not be more than 2 to 4 per cent.

Tests for friction alone should be made at a low speed, because at high speeds the effects of Foucault currents and hysteresis enter and materially increase the apparent friction.

Balance. The perfection of balance of the armature or pulley can be roughly tested by simply running the machine at normal speed and noting if these parts cause any objectionable vibration. Of course, practically every machine produces perceptible vibration when running, but this should not amount to more than a very slight trembling. The balance of a machine can be definitely tested, and the extent of the vibration measured, by suspending the machine or by mounting it on wheels, and running it at full speed. In this case it is better to run the machine as a motor, even though it be actually a generator, in order to avoid the necessity of running it by a belt, which would cause vibration and interfere with the test. If, however, the use of a belt is unavoidable, it should be arranged to run vertically upward or downward so as not to produce any horizontal motion in addition to the vibration of the machine itself. Fig. 40 shows a machine hung up to be tested for balance, and run either as a motor or by the vertical belt indicated by the dotted lines. Any lack of balance will cause the machine to vibrate or swing horizontally, and this motion can be measured on a fixed scale.

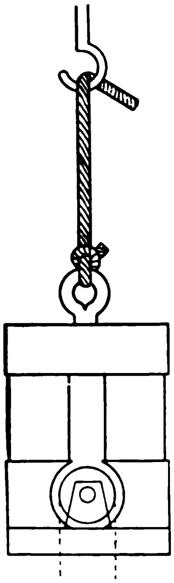


Fig. 40.

Noise. This cannot well be tested quantitatively, although it is very desirable that a machine should make as little noise as possible. Noise is produced by various causes. The machine should be run at full speed, and any noise and its cause carefully noted. A machine—especially the commutator—will nearly always run more quietly after it has been in use a week or more and has worn smooth.

Heating. The proper way to determine the temperature rise in electrical apparatus is by measurements of resistance, before and after operating for a specified time (usually 3 to 4 hours) under rated load.

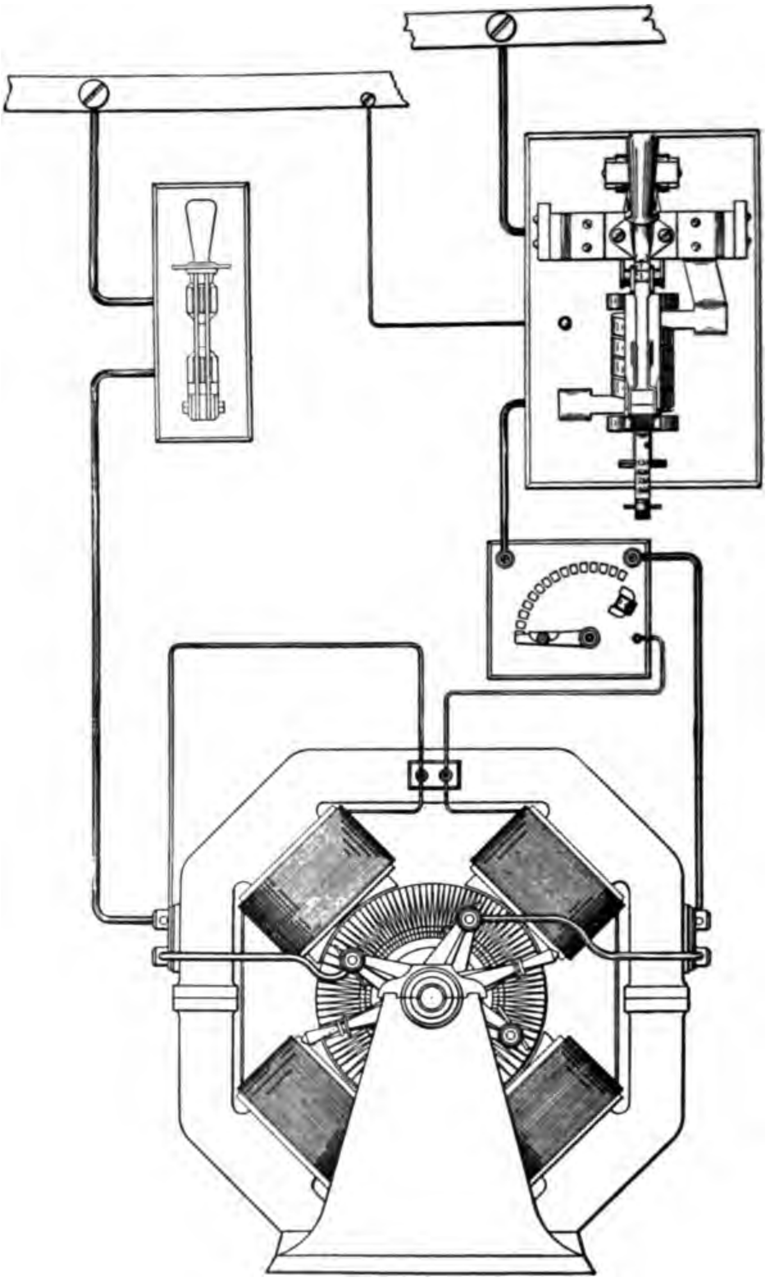
The rise of temperature is:

$$\theta = (238.1 + t)\left(\frac{(R_{t+\theta}}{R_t} - 1\right),$$

in which t is the room temperature in degrees Centigrade, R_t the resistance in ohms at room temperature, and $(R_{t+\theta})$ the final resistance at a temperature elevation of θ° C. The standard room temperature is 25° C; and if it differs from this, the determined rise should be corrected by $\mp\frac{1}{2}$ per cent for each degree C. For ordinary tests it may be assumed that the resistance of copper increases .4 per cent for each degree C rise in temperature. The allowable rise in temperature for field or armature windings is 50° C, hence their resistance for continuous operation at rated load should not be more than 20 per cent in excess of the room temperature. The heating of commutators, collector rings, and brushes that cannot be measured electrically, is tested by thermometers when the machine is stopped, the permissible rise being 50° C; and for bearings and other parts of machines the limit is 40° C. When a thermometer is applied to a surface it should be covered by a pad of cotton or waste cloth, in a shallow, circular box about 1½ inches in diameter. A large pad tends to accumulate heat. When machines are in operation, or in other cases when it is not convenient to measure resistances, especially for excessive temperatures due to abnormal conditions, thermometers may be used to test all stationary parts; but it should be noted that their indications are usually about 5° C lower than those determined by resistances, because the surface is cooler than the interior. A very simple test of heating is to apply the hand to the armature, etc., and if it can be held there without great discomfort, the temperature is not dangerous. Allowance should always be made, however, for the fact that, on account of its heat conductivity, bare metal feels very much hotter than cotton-covered wires, cloth, etc., at the same actual temperatures; but this apparent difference is much less if the hand is kept on for 10 to 20 seconds.

Sparking at the commutator cannot be accurately measured; but it is very objectionable, and in a machine in good order should be hardly perceptible. In any test one should observe carefully whether the sparking is excessive or not; and if so, to what it is due.

An approach to measurement may be made by starting with a lightly loaded machine and gradually increasing the load, meanwhile shifting the rocker-arm and brushes back and forth, and noting at what load it is impossible to find a non-sparking point. In machines the brushes must be shifted to follow the armature reaction as the load increases; but one should always be able to find a place where sparking ceases, within the rated load. In fact, a machine should be able to run with 25 per cent overload before sparking is serious. If a machine begins to spark at 50 per cent of its load, it is clearly only half as useful as it might be, and this may be taken in a sense as a measure of sparking.



WIRING DIAGRAM.

Connections of Single Pole Overload and no Voltage I-T-E Circuit Breaker.

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

PART II

ELECTRICAL RESISTANCE.

Among the most important tests which it is necessary to make in connection with Dynamo-Electric Machinery are those for resistance.

There are two principal classes of resistance tests that must be made in connection with generators and motors. First, the resistance of the wires or conductors themselves, called the *metallic* resistance; and, second, the resistance of the insulation of the wires, known as the *insulation* resistance. The latter should always be as high as possible, because a low insulation resistance not only allows current to leak, but also causes "burn-outs" and other accidents. Metallic resistance, such, for example, as the resistance of the armature or field coils, is commonly tested either by the Wheatstone bridge or by the "drop" (fall-of-potential) method.

The Wheatstone Bridge is simply a number of branch circuits connected as indicated in Fig. 41. A, B, and C are resistances the values of which are known. X is the resistance which is being measured. G is a galvanometer, S its key, and E is a battery of one or two cells controlled by a key K, all being connected as shown. The resistance C is varied until the galvanometer shows no deflection, when the keys K and S are closed in the order named. If the key S should be closed before K, or at the same moment, the

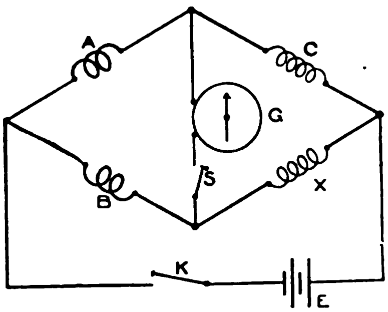


Fig. 41.

inductive effect would produce a pronounced deflection of the galvanometer needle, and thus probably cause confusion. The value of the resistance X is then found by multiplying together resistances C and B, and dividing by A; that is,

$$X = \frac{C \times B}{A}.$$

A very convenient form of this apparatus is what is known as the portable bridge (Fig. 42). This consists of a box containing the three sets of known resistances, A, B, and C, controlled by plugs; also the galvanometer G, and keys K and S, all connected in the proper way. In some cases further convenience is secured by including the battery E in the box; but ordinarily this is not done, and it is necessary to connect one or two cells of battery to a pair of binding-posts placed on the box for that purpose. Resistances from $\frac{1}{10}$ ohm to 100,000 ohms can be conveniently and accurately measured by the Wheatstone bridge. Below $\frac{1}{10}$ ohm the resistances of the contacts in the binding-posts and plugs are apt to cause errors, and therefore special bridges provided with mercury contact cups are used. In fact, in measuring any resistance, care should be taken to make the connections clean and tight.

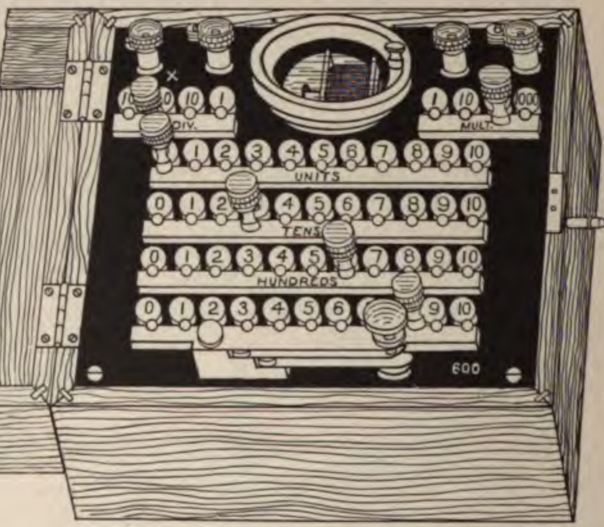


Fig. 42.

The ordinary bridge will not measure above 100,000 ohms, because, if the resistance in the arm B is 100 ohms, 1 ohm in A, and 1,000 ohms in C, then X is 100,000. Sometimes the arms A and B are provided with 1,000-ohm coils in addition to the usual 1-, 10- and 100-ohm coils; or sometimes the arm C contains more than 1,000 ohms in all; in either case the range will be correspondingly increased.

It should be observed, however, that the use of ratios of 1,000: 1, or even 100: 1, is not desirable, since they are likely to multiply any error due to contact resistances, etc. In fact, it is usually better to have the four resistances not very widely different in value; that is, no one of them should be more than ten times greater than any other except when very high or very low resistances are to be measured. The Wheatstone bridge may be used for testing the resistances of almost any field coils that are found in practice. Shunt fields for 110-volt machines usually vary from about 100 or 200 ohms in a 1-H. P. machine to about 5 to 20 ohms in a 100-H. P. machine. If the voltage is higher or lower than 110, these resistances vary as the square of the voltage. Series fields for arc-circuit dynamos vary from about 1 to 20 ohms. In measuring field resistances with the bridge, care must be taken to wait a considerable time after pressing the battery key, before pressing the galvanometer key, in order to allow time for the self-induction of the magnets to disappear.

The bridge may be used also for testing the armature resistance of some machines. But 110-volt shunt machines above 10 H. P. usually have resistances less than $\frac{1}{10}$ ohm, which is below the range of the ordinary bridge, as already stated. For higher or lower voltages the resistance is proportional to the square of the voltage. Arc machines have armatures of about 1 to 20 ohms resistance, and are therefore easily tested by the bridge.

The Drop (or **Fall-of-Potential**) **Method** is well adapted for locating faults quickly, and for testing the armature resistance of most generators and motors, or the resistance of contact between commutator and brushes, or other resistances which are usually only a few hundredths or even thousandths of an ohm. This consists in passing a current through the armature and connections and a known resistance (of, say, $\frac{1}{100}$ ohm), all connected in series, as represented in Fig. 43. The "drop" or fall of potential in the armature and that in the known resistance are compared by connecting a voltmeter first to the terminals of the known resistance (marked 1 and 2), and then to various other points on the circuit, as indicated by the dotted voltmeter terminals at M, N, O, Q, R, and S, so as to include successively each part to be tested. The deflections in all cases are directly proportional to the resistances included between the points touched by the terminals. The current needed depends upon the resistance of the circuit and the sensitiveness of the voltmeter. A bank of lamps or a liquid resistance is used for limiting the current. Instead of using a known resistance, an ammeter may be inserted in series with the resistance to be tested, the latter being then determined by Ohm's law, *viz.*, If E is the voltmeter deflection, and I represents the amperes flowing, the resistance of the part under test is $R = \frac{E}{I}$

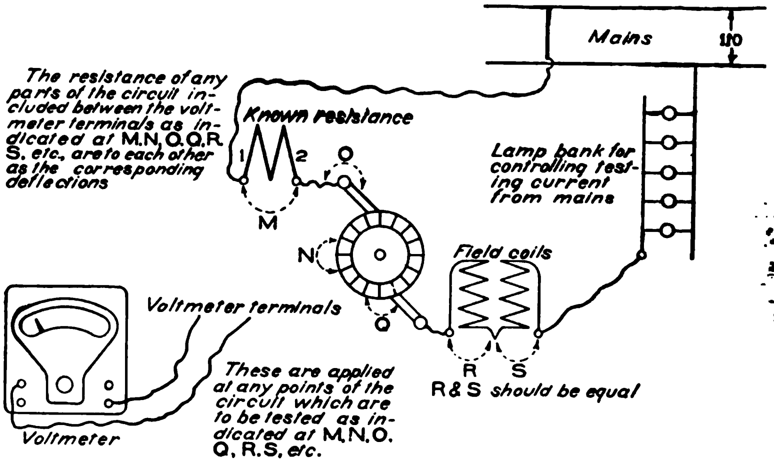
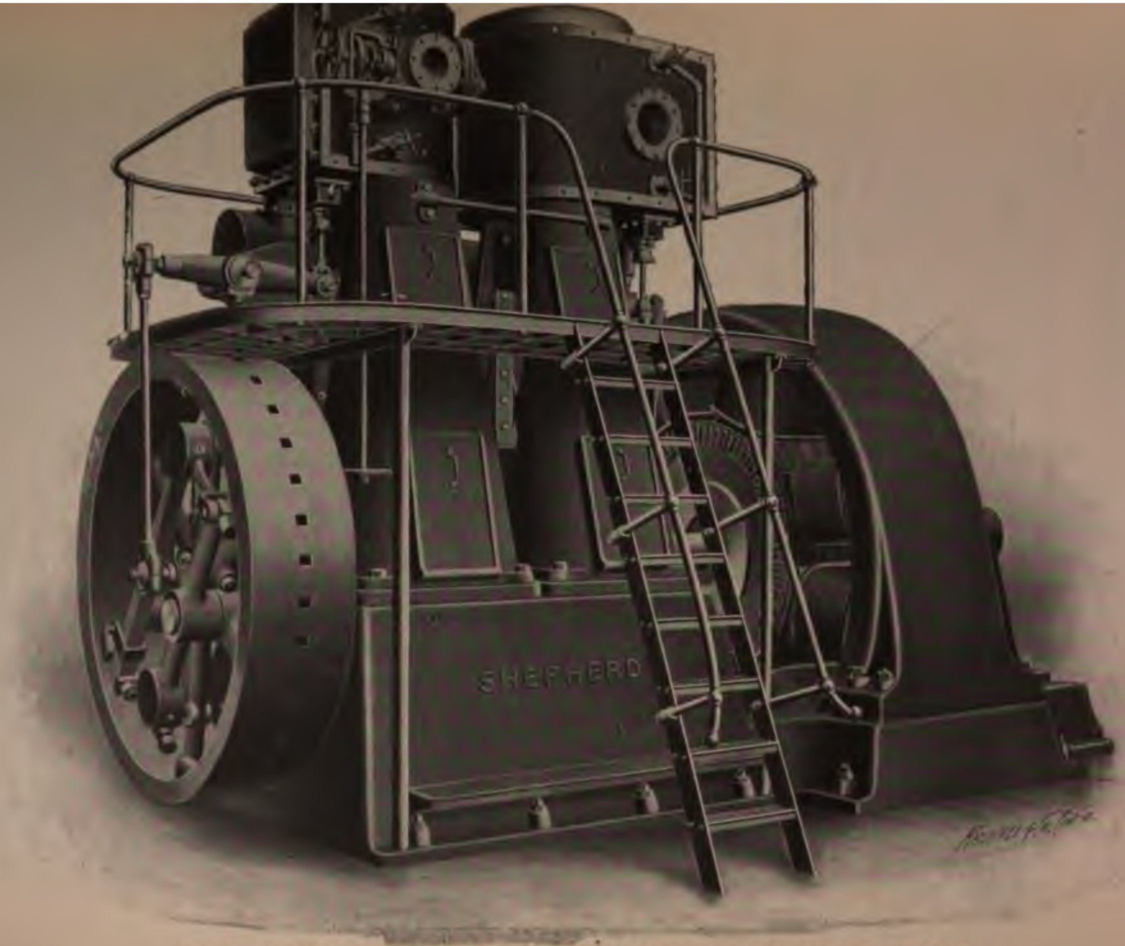

Mains
110
The resistance of any parts of the circuit included between the voltmeter terminals as indicated at M.N.O.Q.R.S. etc., are to each other as the corresponding deflections
Known resistance
1
2
Q
M
N
O
Lamp bank for controlling testing current from mains
Field coils
Voltmeter terminals
These are applied at any points of the circuit which are to be tested as indicated at M.N.O.Q, R.S, etc.
R
S
R & S should be equal
Voltmeter

Fig. 43.

A "station" or a portable voltmeter may be used for the readings, and its terminals may be held in the hands, or they may be conveniently arranged to project from an insulating handle like a two-pronged fork. Usually 10 to 100 amperes and a low-reading voltmeter are needed for low resistances.

It is well to start with a small testing current, and increase it until a good deflection is obtained on the voltmeter. If a current



VERTICAL CROSS-COMPOUND ENGINE DIRECT-CONNECTED TO 400 K.W. DYNAMO.

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of several amperes cannot be had, a few cells of storage battery or some strong primary battery, such as a Bunsen, bichromate, or plunge battery, can be used with a galvanometer or low-reading voltmeter.

The diagram indicates the testing of a machine with series fields. Shunt fields must be connected directly to the line on account of their high resistance; while the armature can be connected as here shown, without being allowed to revolve.

This drop method of testing is also very useful in locating any fault. The two wires leading from the voltmeter are applied to any two points of the circuit, as indicated by the dotted lines —for instance, to two adjacent commutator segments, or to a brush tip and the commutator; any break or poor contact will be indicated immediately by the deflection being larger than at some other similar part. This shows that the fault is between the two points to which the wires are applied. Thus, by moving these along on the circuit, the exact location of any irregularity, such as a bad contact, short circuit, or extra resistance, can be found.

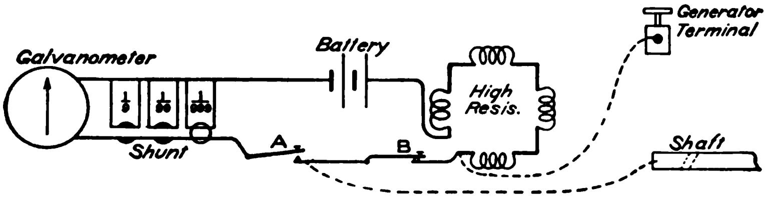

Fig. 44.

The *insulation resistance* of a generator or motor, that is, the resistance between its wires and its frame, should be sufficiently high so that not more than one-millionth of its rated current will pass through it at normal voltage, and it is well to have it still higher. It is therefore beyond the range of ordinary Wheatstone-bridge tests; but two good methods are applicable—the "direct-deflection" and the voltmeter method.

The Direct-Deflection Method is carried out by connecting a sensitive galvanometer, such as a Thomson high-resistance reflecting galvanometer, in series with a known high resistance, usually a 100,000-ohm rheostat, a battery, and keys, as shown in Fig. The galvanometer should be shunted with the $\frac{1}{999}$ coil shunt, so that only $\frac{1}{1000}$ of the current passes through the galvanometer, the machine being entirely disconnected. The keys A and B are closed and the steady deflection noted. It is well to use but one cell of the battery at first, and then increase the number if necessary until a considerable deflection is obtained. The circuit is then opened at the key B, and connected by wires to the binding-post or commutator and to the frame or shaft of the machine, as indicated by dotted lines, so that the machine insulation resistance is included directly in the circuit with the galvanometer and battery. The key A is then closed and the deflection noted. Probably there will be little or no deflection, on account of the high insulation resistance; and the shunt is changed to $\frac{1}{99}$, $\frac{1}{9}$, or left out entirely if little deflection is obtained. In changing the shunt, the key should always be open, otherwise the full current is thrown on the galvanometer. The insulation is then calculated by the formula:

$$\text{Insulation resistance} = \frac{D \times R \times S}{d},$$

in which D is the first deflection without the machine being connected, and *d* the deflection with the machine insulation in the circuit, R the known high resistance, and S the ratio of the shunt. That is, if the shunt is $\frac{1}{999}$ in the first test, and $\frac{1}{9}$ in the second, then S is 100; and if the shunt is out entirely in the second test, S is 1,000. It is safer to leave the high resistance in circuit in the second test, to protect the galvanometer in case the insulation resistance is low. Therefore this resistance must be subtracted from the result to obtain the insulation of the machine itself.

By the above method it is possible to measure 100 megohms or even more. The wires and connections should be carefully arranged to avoid any possibility of contact or leakage, which would spoil the test. If no deflection is obtained, place one finger on the frame and one on the binding-post of the machine, which makes enough leakage to affect the galvanometer and show that the connections are right, thus proving that any poor insulation will be indicated if it exists.

The Voltmeter Test for Insulation Resistance requires a sensitive high-resistance voltmeter, such as the Westcn. Take, for example, the 150-volt instrument, Fig. 45, which usually has ut 15,000 ohms resistance. (A certificate of the exact resiste is pasted inside each case.) Apply it to some circuit or tery, and measure the voltage. This should be as high as sible—say, 100 volts. The insulation resistance of the machine then connected into the cirit, as indicated in Fig. 46. e deflection of the voltmeter less than before, in proportion the value of the insulation istance.

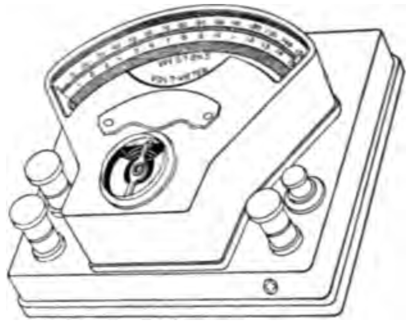

Fig. 45.

The insulation is then found the equation:

ulation resistance $= \frac{D \times R}{d} - R$,

which D is the first and d second deflection, and R the resistance of the voltmeter. If circuit is 100 volts, D is 100; and if d, the deflection through insulation resistance of the machine, is 1 division, the insulan is 1,485,000 ohms. Permanent marks indicating amounts of ulation may be put on the voltmeter scale. When making asurements, the voltage should be the same as that employed in eparing this scale (say, 115 volts). To calculate the scale use is formula:

$$d = \frac{115\ R}{X + R},$$

which X is the insulation resistance (1 megohm, ½ megohm, .), and d is the number of volts, opposite which the correspondg graduation is to be placed to form the new scale. This method es not test very high resistances; but if little or no deflection is tained through the insulation resistance, it shows that the latter at least several megohms — which is high enough for most actical purposes.

The ordinary magneto-electric bell may be used to test insuion by simply connecting one terminal to the binding-post of e machine, and the other to the frame or shaft.

A magneto bell is rated to ring from 10,000 to 30,000 ohms d if it does not ring, it shows that the insulation is more that amount. This limit is altogether too low for proper insulation in any case; and therefore this test is rough, and really shows only whether or not the insulation is very poor or the machine actually grounded.

The magneto is also used for "continuity" tests, to determine whether a circuit is complete, by simply connecting the two terminals of the magneto to those of the circuit. If the bell can be rung, it shows that the circuit is complete; if not, it indicates a break. An ordinary electric bell and cell of battery can be used in place of the magneto.

The insulation of a machine should always be tested for disruptive strength, with a current of at least double the normal working pressure, to see if it will "break down" or be punctured by the current. A transformer motor-dynamo wound to give high voltage is convenient for this.

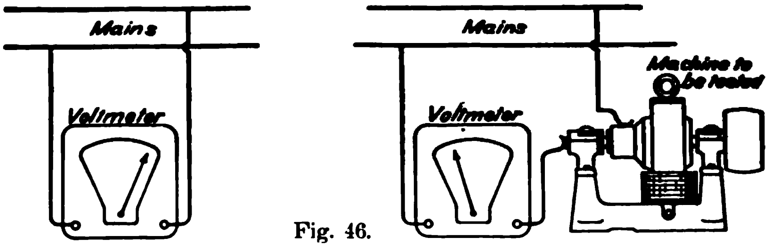

Fig. 46.

Tests of the resistances of generators or motors should propperly be made when the machines are as warm as they get when running continuously at full load. This increases the resistance of conductors and decreases the insulation resistance, but it gives the actual working values.

Voltage. Instruments for measuring voltage (known as voltmeters) are in nearly all cases galvanometers of practically constant resistance. Through them flow currents which are directly proportional to the impressed voltages. A pointer connected to the moving part deflects over a graduated scale. A voltmeter should have as high a resistance as possible—at least several thousand ohms — in order not to take too much current, which might lower its reading on high-resistance circuit or consume too much power. It should not be affected by the magnetism of a generator or motor at any distance over a few feet.

The voltage of any machine or circuit is tested by merely connecting the two binding-posts or terminals of the voltmeter to the two terminals or conductors of the machine or circuit. To get the external voltage of a generator or motor, the voltmeter is usually applied to the two main binding-posts or brushes of the machine. This external voltage is what a generator supplies to the circuit. It is also called the pole difference of potential or terminal voltage, and is the actual figure upon which calculations of the efficiency, capacity, etc., of any machine are based.

A generator for constant-potential circuits should, of course, give as nearly as possible a constant voltage. A plain shunt machine usually falls from 5 to 15 per cent in voltage when its current is varied from nothing to full load. This is due to the I R drop caused by the resistance of the armature circuit, which in turn weakens the field current and magnetism; armature reaction usually occurs also, and still further lowers the external voltage. This variation is undesirable, and is usually avoided by regulating the field magnetism (varying the resistance in the field circuit) or by the use of compound-wound generators. A compound-wound dynamo should not fall appreciably from no load to full load; in fact, if it is "over-compounded" it should rise 5 per cent or more in voltage to make up for loss on the wiring.

The voltage of a constant-current generator is not important. The current should be carefully measured by an ammeter, but little attention is paid to the voltage in practical working; in fact, it changes constantly with variations in the load. But it is necessary, of course, to measure it in making efficiency or other exact tests.

A simple and fairly accurate method of measuring voltage is by means of ordinary incandescent lamps. A little practice enables one to tell whether a lamp has its proper voltage and brightness. In this way it is easy to tell if the voltage is even one or two per cent above or below the normal point. Voltages less than the ordinary can be tested by using low-voltage lamps or by estimating the brightness of high-voltage lamps. For example, a lamp begins to show a very dull red at one-third and a bright red at one-half its full voltage. Voltages higher than that of one lamp can be tested by using lamps in series. Thus 1,000 volts can be measured by using 10 lamps in series, and so on.

Current. This is measured by an ammeter (Fig. 47), which is usually cheaper than a voltmeter because it contains a comparatively small amount of wire. In testing the current of a generator or motor, it is necessary only to connect an ammeter, of the proper range, in series with the machine to be tested, so that the whole current passes through the instrument or its shunt. To test the current in the armature or the field alone, the ammeter is connected in series with the particular part. To avoid mistakes in the case of a shunt-wound generator, it is well to open the external circuit entirely in testing the current used in the field coils; for the same reason the brushes of a shunt motor should be raised before testing the current taken by the field.* In a constant-current or series-wound dynamo, the same current flows through all parts of the machine and the circuit; consequently the measurement of current is very simple.

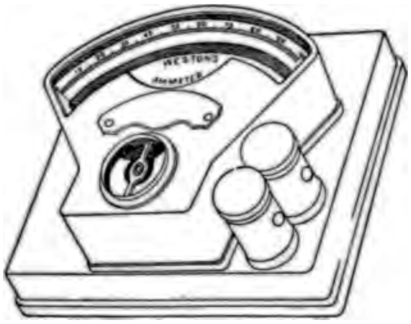

Fig. 47.

If an ammeter cannot be had, current can be measured by inserting a known resistance in the circuit and measuring the difference of potential between its ends. The volts thus indicated, divided by the resistance in ohms, gives the number of amperes flowing. If a known resistance is not at hand, the resistance of a part of the wire forming the circuit can be obtained from its diameter measured with a screw caliper or a wire gauge, by referring to any of the tables of resistances of wires; or the resistance can be measured by a Wheatstone bridge (Fig. 42), or by putting an ammeter, when one can be spared, into the circuit, while the voltmeter is connected. The volts divided by the amperes gives the resistance in ohms between the points to which the voltmeter is connected. Two connections can be attached permanently to two points on the circuit, and an ammeter temporarily inserted, and for every reading of the ammeter the corresponding reading of the voltmeter attached to these connections may be noted. Then, by keeping a list of these readings, the amperes can be found at any future time, by connecting the voltmeter to the two permanent contacts. This preliminary use of the ammeter amounts to measuring the resistance between the two contacts, and allows for the increase of resistance when the current and heating increase. In any case it is convenient to use a length of wire, or a distance between contacts, which will give an even amount of resistance, say, 1-10 or 1-100 ohm. And, as with large current the resistance will be fractional, care must be taken to avoid errors in multiplying, etc.

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* These instructions are to be followed when only one ammeter is to be had; otherwise one could be placed in the field circuit, and another in the circuit from the starting box to the independent armature terminal.

In testing the output of a generator, it is often quite a problem to dispose of the current produced. A bank of lamps, for example, to use the whole current generated by a dynamo of 110 volts and 1,000 amperes, would be very expensive. A sufficient number of resistance-boxes for the purpose would also be very costly. The best way is to drive the generator by a motor, and connect it up in parallel with the line. In this way most of the power is returned instead of being wasted. If a motor cannot be had, the simplest and cheapest way to consume a large current is to place two plates of iron in a common tub or trough filled with a weak solution of carbonate of soda (common washing soda), which is better than almost any other solution because it neither gives off fumes nor eats the electrodes. The main conductors are connected to the two plates, respectively, and the current passes through the solution. The resistance and current are regulated by varying the distance between the plates, the depth they are immersed in the liquid, and the strength of the solution. The energy may be suf-

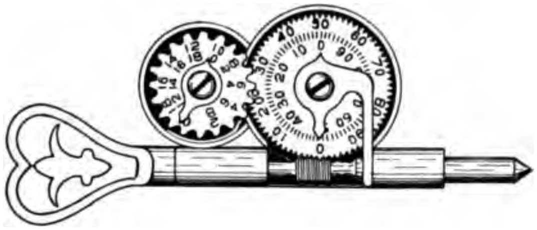

Fig. 48.

ficient to boil the liquid, but this does no harm. Three to ten amperes per square inch of active surface of plate may be allowed.

Speed. This is usually measured by the well-known **speed counter** (Fig. 48), consisting of a small spindle which turns a wheel one tooth each time it revolves. The point of the spindle is held against the center of the shaft of the generator or motor for a certain time, say, one minute or one-half minute, and the number of revolutions is read off from the position of the wheel.

Another instrument for testing the number of revolutions per minute is the **tachometer.** The stationary form of this instrument is shown in Fig. 49. It must be belted by a string, tape, or light leather belt to the machine the speed of which is to be tested. If the sizes of the pulleys are not the same, their speeds are inversely proportional to their diameters. The portable form of this instrument (Fig. 50) is applied directly to the end of the shaft of the machine, like the speed counter. The tip can be slipped upon either one of the three spindles, which are geared together, according as the speed is near 500, 1,000, or 2,000 revolutions. These instruments possess the great advantage over the speed counter that they instantly point on the dial to the proper speed, and they do not require to be timed for a certain period.

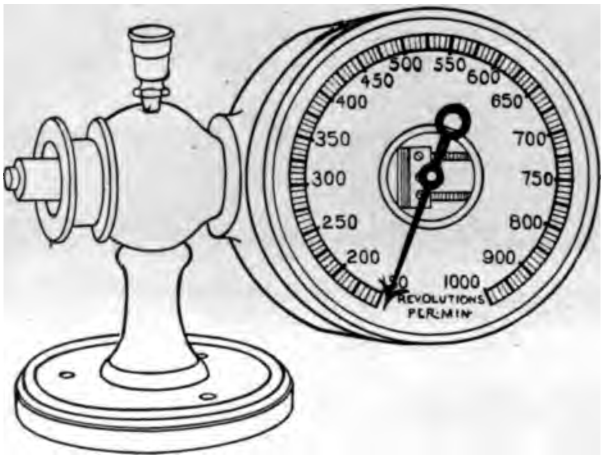

Fig. 49.

A simple way to test the speed in revolutions per minute is to make a large black or white mark on the belt of a machine, and note how many times the mark passes per minute ; the length of the belt divided by the circumference of the pulley gives the number of revolutions of the pulley for each time the mark passes. The number of revolutions of the pulley to one of the belt can also be easily determined by slowly turning the pulley or pulling the belt until the latter makes one complete trip around, at the same time counting the revolutions of the pulley. If the machine has no belt, it can be supplied with one temporarily for the purpose of the test, a piece of tape with a knot or an ink mark being sufficient. Care should be taken in all these tests of speed with belts not to allow any slip ; for example, in the case of the tape belt just referred to, this belt should pass around the pulley of the machine and some light wheel of wood or metal which turns so easily as not to cause any slip of the belt on the pulley of the machine.

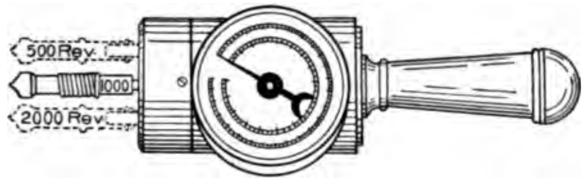

Fig. 50.

Torque or **Pull** is measured in the case of a motor by the use of a Prony brake. This consists of a lever LL of wood, clamped on the pulley of the machine to be tested, as indicated in Fig 51. The pressure of the screws SS is then adjusted by the wing-nuts until the friction of the clamp on the pulley is sufficient to cause the motor to take a given current, and the speed is then noted. Usually, the maximum torque or pull is the most important to test; and this is obtained in the case of a constant-potential motor by tightening the screws SS until the motor draws its full current as indicated by an ammeter. What the full current should be, is usually marked on the name-plate ; if not, it may be assumed to be about 8 amperes per H. P. for 110-volt motors, 4 amperes per H. P. for 220-volt, and 1 3-4 amperes per H. P. for 500-volt motors. If the machine is rated in kilowatts, the full current in amperes can be found by multiplying by 1,000 and dividing by the voltage of the machine. The torque or pull is measured known weights, or more conveniently by a spring balance P. If desired, the test may also be made at three-quarters, one-half, or any other fraction of the full current.

The torque or pull in pounds which should be obtained, can also be calculated from the power at which the machine is rated, by the formula;

$$\text{Torque} = \frac{\text{H. P.} \times 33{,}000}{6.28 \times S},$$

in which H. P. is the horse-power of the machine at full load, and S is the speed of the machine in revolutions per minute at full load. Torque is given at unit radius, commonly pounds at one foot. The pull at any other radius is converted into torque by multiplying by the radius; 1, 2, and 4 ft. are convenient radii or lengths of lever for measuring pull. One H. P. produced at a speed of 1,000 revolutions requires a pull of 5.25 pounds at end of 1-foot lever; at 500 revolutions, twice as much; at 2,000 revolutions half as much; and so on. If the lever is 4 feet, the pull is one-fourth as much, etc.

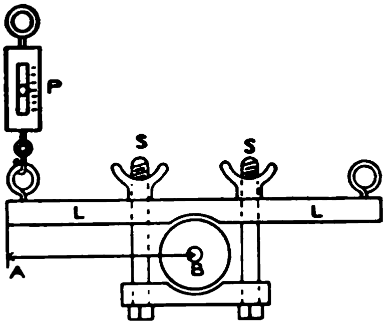

Fig. 51.

The Torque of a Generator, that is, the power required to drive it, is very conveniently determined by operating it as a motor, and testing it by the Prony brake as described above, the torque of a generator being practically equal to that of a motor under similar conditions.

Power. The electrical power of a generator or motor is found by testing the voltage and current at the terminals of the machine, as already described, and multiplying the two together, which gives the electrical power of the machine in watts.* Watts are converted into horse-power by dividing by 746, and into kilowatts by dividing by 1,000.

The mechanical power of a generator or motor, that is, the power required for or developed by it, is found by multiplying its pull by its speed and by the circumference on which the pull is measured, and dividing by 33,000. That is,

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*In testing an alternating-current machine, a wattmeter should be employed instead of a voltmeter and an ammeter, as explained later.

$$\text{Horse-power} = \frac{P \times S \times 6.28 \times R}{33{,}000},$$

in which P is the pull in pounds, S the speed in revolutions per minute, and R the radius in feet at which P is measured.

Efficiency. This is determined in the case of a generator by dividing the electrical power generated by it by the mechanical power required to drive it; that is,

$$\text{Efficiency of generator} = \frac{\text{Electrical power}}{\text{Mechanical power}}.$$

The efficiency of a motor is the mechanical power developed by it, divided by the electrical power supplied to it; that is,

$$\text{Efficiency of motor} = \frac{\text{Mechanical power}}{\text{Electrical power}}.$$

These are the **actual** or **commercial efficiencies** of these machines, and should be at least 90 per cent at rated load in machines of 10 H. P. and over.

The so-called "electrical efficiency" is misleading and of little practical importance, and should not be considered in commercial work. The mechanical and electrical power in the above equations are determined as already explained.

It is usually more convenient to test the efficiency of a generator by testing it as a motor with a Prony brake. But the efficiency of a generator may be determined very easily by driving it with a calibrated electric motor, that is, one in which the power developed for any given number of volts and amperes consumed is known. Then it is only necessary to measure the watts supplied by the generator when the motor is running at a certain power, and the efficiency of the generator is *the watts ÷ the known power*.

Another method is to employ two identical machines, one used as a moter driving the other as a generator. The shafts of the two machines should be directly connected by some form of coupling; a belt may be used, but its friction would cause a small loss. The watts produced by the generator, divided by the watts consumed by the motor, is the combined efficiency of the two machines; and the efficiency of each is the square root of that fraction. For example, if the combined efficiency is .81, then that of each machine is .90, since .90 × .90 = .81. This assumes that the two efficiencies are equal, which is sufficiently correct if the machines are exactly alike. The current from the generator may be used to help feed the motor, and then only the difference in current need be supplied. This latter current represents the inefficiency or losses from friction, etc., in both machines.

To test in this way, connect both machines in parallel with the source of current; couple or belt them together; and then weaken the field, or shift the brushes of the machine which is to be used as a motor, so that it will speed up and drive the other as a dynamo, or cause it to drive the other by putting a large pulley on it. In this way the motor will consume current from the circuit while the generator yields current to the circuit. Both currents are measured and the efficiencies calculated.

The efficiency of a motor-generator or ordinary converter is very easily determined by simply measuring the input and output in watts (by wattmeters or by ammeters and voltmeters for direct currents), and dividing the latter by the former.

These electrical methods of testing are preferable to mechanical, for the reason that the volts and amperes can be easily and accurately measured, and their product gives the power in watts.* Mechanical measurements of power by dynamometer or other means are difficult, and usually not very accurate.

Separation of Losses. The total losses in a generator or motor, except that caused by the electrical resistance of the armature when carrying the full current, can be closely determined at once by noting the current required to run the machine free as a motor. In a machine of 90 per cent efficiency, this should not amount to more than about 8 per cent of the current required to give rated power. Consequently the easiest way to test a machine is to run it as a motor without load.

The various losses of power that occur in a generator or motor may be determined and separated from each other as follows:

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* When alternating-current machinery is being tested use wattmeters.

Take a generator, for example, and drive it with another machine used as a motor in the manner described for testing friction. The motor should previously be calibrated, that is, tested to determine the exact mechanical power it develops for each amount of electrical power in watts supplied to it, as described for testing efficiency. A simple, shunt-wound motor on a constant-potential circuit is best suited to the purpose. The generator is first driven at normal speed with no field magnetism and with the brushes lifted; then the actual power developed by the motor equals the power lost in the generator by the friction of bearings and belt. The brushes are then adjusted in contact with the commutator, with the usual pressure. The increase in the power of the motor is equal to the brush friction.

Finally, excite the field magnet to full strength, and the increase in the power exerted by the motor is equal to the combined losses due to the Foucault or eddy currents and hysteresis in the iron core of the armature, provided there is no considerable side pull on the armature. The power wasted in Foucault currents varies as the square of the speed, while the hysteretic loss is only directly proportional to speed; hence the two may be separated by testing the machine at different speeds.

For example, let us call x and y the losses due to hysteresis and Foucault currents, respectively, at full speed; A the power consumed by both at full speed; and B the power consumed at half speed. Then $A = x + y$, and $B = \frac{x}{2} + \frac{y}{4}$; hence, by eliminating x, we have $y = 2A - 4B$. That is the Foucault loss is twice the power consumed by both at full speed minus four times the power consumed by both at half speed. The hysteresis loss $= A - y$. If eddy currents are developed in the copper conductors of the armature, they will increase the apparent Foucault loss as determined by the above test, since they also vary as the square of the speed. The power wasted by eddy currents might be found by testing the armature without any conductors upon it. This could be done only before the armature is wound or by unwinding it, neither of which is practicable except in the place where it is made. Ordinarily, however, eddy currents in the conductors do not amount to much unless they are ve large, and even then the use of stranded conductors or conductors embedded in slots in the iron core largely overcomes the trouble.

Friction of the air might also increase the apparent Foucault loss; but it usually causes only a very small loss, and is almost impossible to separate except by running the machine in a vacuum, which is, of course, impracticable. The other losses are quite easily measured and separated, as follows :

The number of watts used in the field can be measured by a voltmeter and ammeter, or it can be calculated by the formula: $\text{Watts} = \frac{E^2}{R} = I^2R = EI$, in which E is the voltage, R the resistance, and I the current. It is sufficient if any of these two quantities are known. The loss in the armature conductors, due to ohmic resistance is found by multiplying the square of the current in the armature at full load by the armature resistance; in fact, this is usually called the "I^2R loss." This should not be more than 1 to 3 per cent in a constant-potential generator or motor, whether it be alternating-or direct-current. The sum of all the losses make up the difference between the total power consumed by the machine and the useful power that it develops.

The ordinary values of the various losses in a good generator or motor of 25 H. P. are approximately as follows :

Useful power developed.............	.about 92	per cent.
Used in magnetizing field..........	.about 1 to 2	"
Loss in armature resistance (I^2R)...	" 1 to 2	"
Friction of bearings	.about 2	"
Friction of brushes.....................	" ½	"
Friction of air..........................	" ½	"
Hysteresis in armature core	" 1½	"
Foucault currents in armature core....	" 1½	"

Measurement of Power in A. C. Circuits. In circuits carrying alternating currents and having some inductive load either in the form of motors or arc lamps or a partly loaded transformer, etc., the ordinary method of determining the power, by voltmeter and ammeter measurements, is not applicable, as the current is seldom in phase with the E. M. F., and therefore the product *volts* × *amperes* is not the true power.

There are several means for determining the true power of an A. C. circuit, the simplest being an indicating wattmeter. A wattmeter is an electro-dynamometer provided with two coils, a fixed one of coarse wire, the other movable and of fine wire. This movable coil is connected in series with a large non-inductive resistance, so that the time-constant of the fine-wire circuit is extremely small; and hence its impedance is practically equal to its resistance; the current in, and resulting field of, the fine-wire coil will under these conditions be practically in phase with the potential difference across its terminals. The field produced by the coarse-wire coil is directly proportional to the current flowing through it at any instant. Hence, the couple acting on the fine-wire coil is proportional at a given instant to the product of these fields; so that the reading of the instrument, which depends on the mean value of the couple, will be proportional to the mean power, and, by providing the instrument with the proper scale, it can be made to read directly in watts.

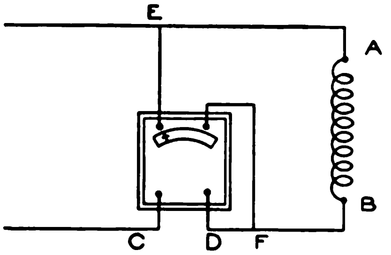

Fig. 52.

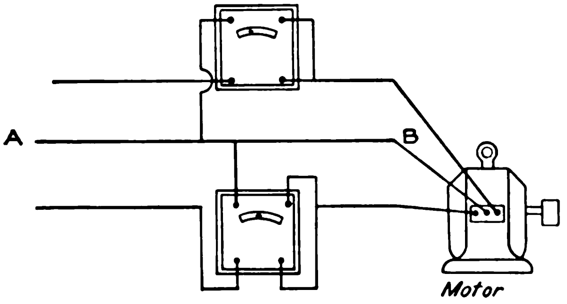

Fig. 53.

In Fig. 52, A B represents an inductive load—say, a single-phase motor—of which the power input is to be determined; C D the terminals of the thick-wire coil (current-coil) of the wattmeter; and E F the pressure-coil terminals. When connected as above indicated, the wattmeter indicates directly the power in watts supplied. In the case of a two-phase system, where the two circuits are independent, the power may be measured by placing a wattmeter in each phase, as shown in Fig. 52, and adding the two readings. If the motor be connected up as shown in Fig. 53,* where A B forms a common return, the wattmeters are placed as indicated, *care being taken to place the current-coils in the outside mains;* and the power supplied is equal to the sum of the two wattmeter readings.

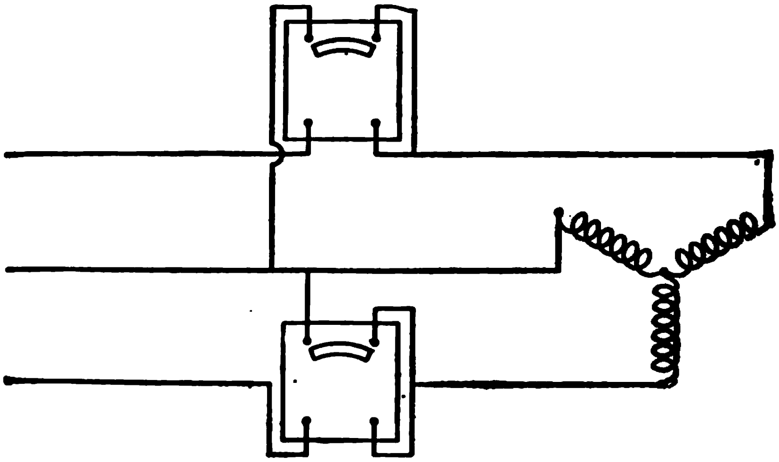

Fig. 54*a*.

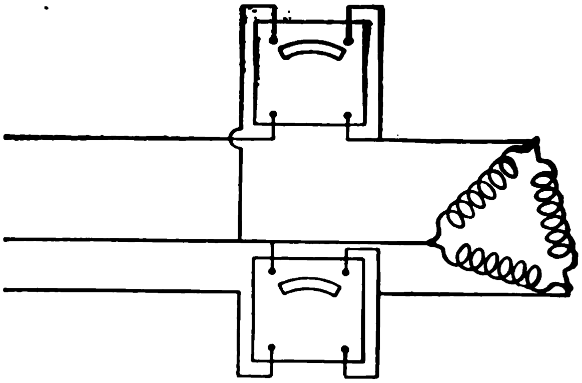

Fig. 54*b*.

The power of a balanced or unbalanced three-phase system can be determined by the use of two wattmeters connected as

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[*] This form of connection is possible only when the generator has two independent windings, one for each phase.

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shown in Fig. 54, *a* and *b*. The current-carrying coils are placed in series with two of the wires, and the pressure-coil respectively connected between these two mains and the third wire. The *algebraic* sum of these two wattmeter readings gives the true power supplied. When the power factor of the system is less than .5, one of the wattmeters will read negatively It is sometimes difficult to determine whether the smaller readings are negative or not. If in doubt, give the wattmeter a separate load of incandescent lamps, and make the connections such that both instruments deflect properly; then reconnect them to the load to be measured. If the terminals of one instrument have to be reversed, the readings of that wattmeter are negative.

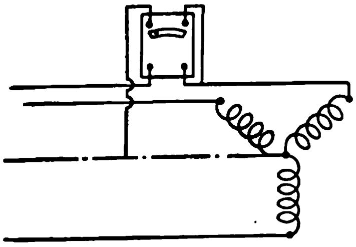

Fig. 55.

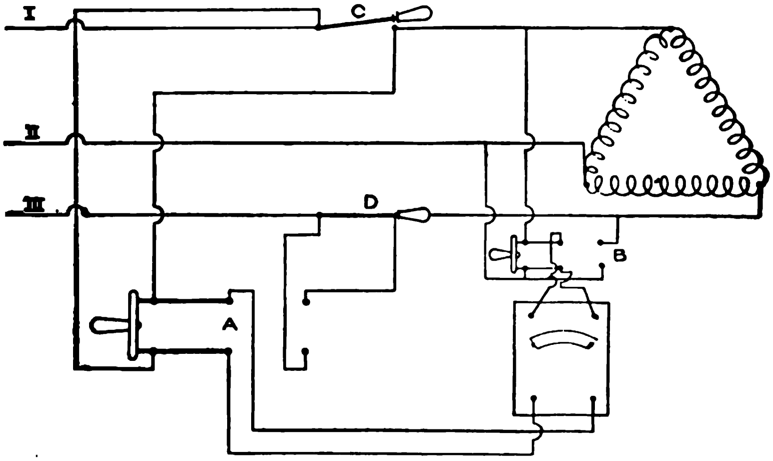

Fig. 56.

To measure the power of a balanced 4-wire 3 phase system, one wattmeter may be connected as shown in Fig. 55, and the wattmeter reading multiplied by 3. Usually, however, a 4-wire 3-phase system is unbalanced; and to determine the power supplied under this condition, three wattmeters should be employed, one for each phase, the power supplied being equal to the algebraic sum of all three readings.

It is obvious that in any of the above instances one wattmeter could be employed, provided the necessary switches are furnished. Assuming, for example, the 3-phase 3-wire case, one wattmeter would require switch connections as shown in Fig. 56. A is a double-pole switch, which, when thrown to the left, places the current-coil of the wattmeter in series with the conductor of No. I, and, when thrown to the right, places it in series with No. III. Similarly, switch B changes the pressure terminals from between I and II to III and II; while switches C and D are short-circuiting switches, one of which is closed previous to removing the current-coil from one phase to the other, and the other one opened after the coil is in position as indicated.

LOCALIZATION AND REMEDY OF TROUBLES.

The promptness and ease with which any accident or difficulty with electrical machinery can be dealt with, will always have much to do with the success of a plant. The following list of troubles, symptoms, and remedies for the various types and sizes of dynamos and motors in common use, has been prepared to facilitate the detection and elimination of such difficulties.

It is evident that the subject is somewhat complicated and difficult to handle in a general way, since so much depends upon the particular conditions in any given case, every one of which must be included in the table in such a way as to distinguish it from all others Nevertheless, it is remarkable how much can be covered by a systematic statement of the matter, and nearly all cases of trouble most likely to occur are covered by the table, so that the detection and remedy of the defect will result from a proper application of the rules given.

It frequently happens that a trifling oversight, such as allowing a wire to slip out of a binding-post, will cause as much annoyance and delay in the use of electrical machinery as the most serious accident. Other troubles, equally simple but not so easily detected, are of frequent occurrence.

The rules are made, as far as possible, self-explanatory; but a statement of the general plan followed and its most important features will facilitate the understanding and use of the table.

USE OF THE TABLE OF TROUBLES.

In the use of this table, the principal object should be to separate clearly the various causes and effects from one another. A careful and thorough examination should first be made; and, as far as possible, one should be perfectly sure of the facts, rather than attempt to guess what they are and jump at conclusions. Of course, general precautions and preventive measures should be taken before any troubles occur, if possible, rather than to wait until a difficulty has arisen. For example, one should see that the machine is not overloaded or running at too high voltage, and should make sure that the oil-cups are not empty. Neglect and carelessness with any machine are usually and deservedly followed by accidents of some sort. It is usually wise to stop the machine when any trouble manifests itself, even though it does not seem to be very serious. It is often practically impossible to shut down; but even then, spare apparatus should be ready. The continued use of defective machinery is a common but very objectionable practice.

The general plan of the table is to divide all troubles that may occur to generators or motors, into ten classes, the headings of which are the ten most important and obvious bad effects produced in these machines, *viz.:*

I. Sparking at Commutator.
II. Heating of Commutator and Brushes.
III. Heating of Armature.
IV. Heating of Field Magnets.
V. Heating of Bearings.
VI. Noisy Operation.
VII. Speed not right.
VIII. Motor stops or fails to start.
IX. Dynamo fails to generate.
X. Voltage not right.

Any one of these general effects is evident, even to the casual observer, and still more so to any person making a careful examination; hence nine-tenths of the possible cases can be eliminated immediately.

The next step is to find out which particular one of the eight or ten causes in this class is responsible for the trouble. This requires more careful examination, but nevertheless can be done with comparative ease in most cases. One cause may produce two effects, and, *vice versa*, one effect may be produced by two causes; but the table is arranged to cover this fact as far as possible. In a complicated or difficult case it is well to read through the entire table and note what causes can possibly apply. Generally there will not be more than two or three; and the particular one can be picked out by following the directions, which show how each case may be distinguished from any other.

I. SPARKING AT THE COMMUTATOR.

This is one of the most common of troubles, being often quite serious because it burns and cuts the commutator and brushes, at the same time producing heat that may spread to and injure the armature or bearings. Any machine having a commutator is liable to it, including practically all direct-current and some alternating-current machines. The latter usually have continuous collecting rings not likely to spark; but self-exciting or composite-wound alternators, rotary converters, and some alternating-current motors have supplementary direct-current commutators. A certain amount of sparking occurs normally in most constant-current dynamos for arc lighting, where it is not very objectionable, since the machines are designed to stand it and the current is small.

CAUSE 1. **Armature carrying too much current,** due to (*a*) overload (for example, too many lamps fed by dynamo, or too much mechanical work done by motor; a short circuit, leak, or ground on the line may also have the effect of overloading a dynamo); (*b*) excessive voltage on a constant-potential circuit, or excessive amperes on a constant-current circuit. In the case of a motor, any friction, such as armature striking pole pieces, or a shaft not turning freely, may have the same effect as overload.

SYMPTOM. Whole armature becomes overheated, and belt (if any) becomes very tight on tension side, sometimes squeaking because of slipping on pulley. Overload due to friction is detected by stopping the machine, and then turning it slowly by hand. (See V and VI, 2.)

REMEDY. (*a*) Reduce the load; or eliminate the short circuit, leak, or ground on the line; (*b*) decrease size of driving pulley, or (*c*) increase size of driven pulley; (*d*) decrease magnetic strength of field in the case of a dynamo, or increase it in the case of a motor. If excess of current cannot satisfactorily be overcome in any of the above ways, it will be necessary to change the machine or its winding. Overload due to friction is eliminated as described under V and VI, 2.

If the starting or regulating rheostat of a motor has too little resistance, it will cause the motor to start too suddenly and to spark badly at first. The only remedy is more resistance in the box.

Cause 2, **Brushes not set at the neutral point.**

Symptom. Sparking varied by shifting the brushes with rocker-arm.

Remedy. Carefully shift brushes backwards or forwards until sparking is reduced to a minimum. This can be done by simply moving the rocker-arm. If only slightly out of position, heating alone may result, without disarrangement being bad enough to show sparking. If the brushes are not exactly opposite in a bipolar, 90° apart in a four-pole machine, and so on, they should be made so, the proper points of contact being determined by counting the commutator-bars or by careful measurement.

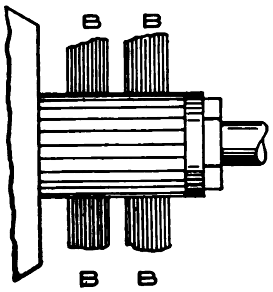

Fig. 57.

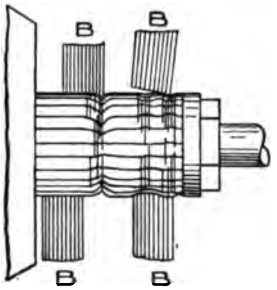

Fig. 58.

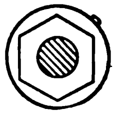

Fig. 59.

The usual position for brushes is opposite the spaces between the pole pieces, but in some machines they must be set in line with centers of pole pieces or at some other point. If the brushes are set exactly wrong, this will cause a dy fail to generate, and a motor to fail to start, and will bl

circuit-breaker. (See IX, 6.)

Cause 3. **Commutator rou**

more "high bars" projecting be

flat bars, commonly called **flats,** or **projecting mica,** any one of which causes the brushes to vibrate or to be actually thrown out of contact with the commutator (Figs. 58 and 59). Hard mica between the bars, which does not wear as rapidly as the copper, will prevent good contact or throw brushes off.

Symptom. Note whether there is a glaze or polish on the commutator, which shows smooth working; touch revolving commutator with tip of finger nail, and the least roughness is perceptible; or feel brushes to see if there is any jar. If the machine runs at high voltage (over 250), the commutator or brushes should be touched with a stick or quill to avoid danger of shock. In the case of an eccentric commutator, careful examination shows a rise and fall of the brush when the commutator turns slowly, or a chattering of brush when it is running fast. Sometimes, by sighting in line with brush contact, one can see daylight between commutator and brush, owing to brush jumping up and down.

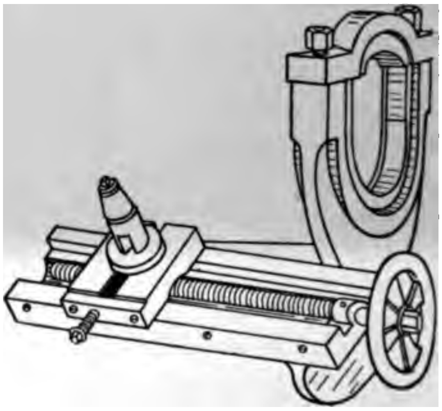
Fig. 60.

Remedy. Smooth the commutator with a fine file or fine sandpaper, which should be applied on a block of wood that exactly fits the commutator (being careful to remove any sand remaining afterward; and *never use emery*). If commutator is very rough or eccentric, the armature should be taken out and put in a lathe, and the commutator turned off. Large machines often have a slide-rest attachment (Fig. 60), so that the commutator can be turned off without removing the armature. This is clasped on the pillow-block after removing the rocker-arm.

For turning off a commutator, a diamond-pointed tool should be used, this being better than either a round or square end. It should have a very sharp and smooth edge; and only a fine cut should be taken off each time in order to avoid catching in or tearing the copper, which is very tough. The surface is then finished.

by applying a "dead smooth" file while the commutator revolves rapidly in the lathe. Any particles of copper should then be carefully removed from between the bars.

To have the commutator wear smooth and work well, it is desirable to have the armature shaft move freely back and forth about an eighth of an inch in the bearings while it is running. A commutator should have a glaze of a brown or bronze color. A very bright or scraped appearance does not indicate the best condition. Sometimes a very little vaseline or a drop of oil may be applied to a commutator that is rough. Too much oil is very bad, and causes the following trouble:

Cause 4. **Brushes make poor contact with commutator.**

Symptom. Close examination shows that brushes touch only at one corner, or only in front or behind, or there is dirt on surface of contact. Sometimes, owing to the presence of too much oil or from other cause, the brushes and commutator become very dirty, and covered with smut. They should then be carefully cleaned by wiping with oily rag or benzine, or by other means.

Occasionally a "glass-hard" carbon brush is met with. It is incapable of wearing to a good seat or contact, and will touch at only one or two points. Some carbon brushes are of abnormally high resistance, so that they do not make good contact. In such cases new brushes should be substituted.

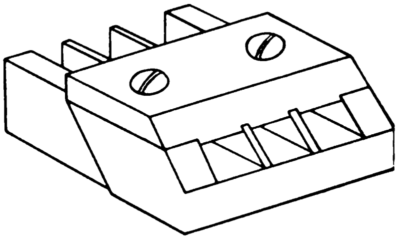

Fig. 61.

Remedy. Carefully fit, adjust, or clean brushes until they rest evenly on commutator, with considerable surface of contact and with sure but not too heavy pressure. Copper brushes require a regular brush jig (Fig. 61). Carbon brushes can be fitted perfectly by drawing a strip of sandpaper back and forth between them and the commutator while they are pressing down. A band of sandpaper may be pasted or tied around the commutator, and the armature then slowly revolved by hand or by power while the brushes are pressed upon it.

It sometimes happens that the brushes make poor contact because the brush-holders do not work freely.

CAUSE 5. **Short-circuited or reversed coil or coils in armature.**

SYMPTOM. A motor will draw excessive current, even when running free without load. A dynamo will require considerable power, even without any load. For reversed coil, see III, 5.

The short-circuited coil is heated much more than the others, and is liable to be burnt out entirely; therefore the machine should be stopped immediately. If necessary to run machine in order to locate the trouble, one or two minutes is long enough; but this may be repeated until the short-circuited coil is found by feeling the armature all over.

An iron screw-driver or other tool held between the field magnets near the revolving armature, vibrates very perceptibly as the short-circuited coil passes. Almost any armature, particularly one with teeth, will cause a slight but rapid vibration of a piece of iron held near it; but a short circuit produces a much stronger effect only *once* per revolution. Care should be taken not to let the piece of iron be drawn in and jam the armature.

The current pulsates and torque is unequal at different parts of a revolution, these being particularly noticeable when several coils are short-circuited or reversed and the armature is slowly turned. If a large portion of the armature is short-circuited, the heating is distributed and is harder to locate. In this case a motor runs very slowly, giving little power but having full field magnetism. A short-circuited coil can also be detected by the drop-of-potential method. For dynamos, see IX, 3.

REMEDY. A short circuit is often caused by a piece of solder or other metal getting between the commutator-bars or their connections with the armature; and sometimes the insulation between or at the ends of these bars is bridged over by a particle of metal. In any such case the trouble is easily found and corrected. If, however, the short circuit is in the coil itself, the only effective remedy is to rewind the coil.

One or more "grounds" in the armature may produce effects similar to those arising from a short circuit. (See Cause 7.)

CAUSE 6. **Broken circuit in armature.**

SYMPTOM. Commutator flashes violently while running, and commutator-bar nearest the break is badly cut and burnt; but in this case no particular armature coil will be heated as in the last case; and the flashing will be very much worse, even when turning slowly. This trouble, which might be confounded with a bad case of "high bar" in commutator (Cause 3), is distinguished therefrom by slowly turning the armature, when violent flashing will continue if circuit is broken; but not with "high bar" unless it is very bad, in which case it is easily felt or seen. A very bad contact has almost the same effect as a break in the circuit.

Remedy. A break or bad contact can be located by the "drop" method (page 63) or by a continuity test (page 68). The trouble is often found where the armature wires connect with the commutator, and not in the coil itself, and the break may be repaired or the loose wire properly fastened. If the trouble is due to a broken commutator connection, and cannot be fixed, the disconnected bar may be temporarily connected to the next by solder, or the brushes may be "staggered," that is, one put a little forward and the other back so as to bridge over the break (Fig. 62). It may be impracticable to "stagger" radial and some other arrangements of brushes, but usually a brush is thick enough to make contact with more than one commutator bar. If the break is in the coil itself, rewinding is generally the only cure. But this may be remedied temporarily by connecting together by wire or solder the two commutator-bars or coil-terminals between which the break exists. It is only in an emergency that armature coils should be cut out or commutator bars connected together, or other makeshifts resorted to; but it sometimes avoids a very undesirable stoppage. A very rough but quick and simple way to connect two commutator bars, is to hammer or otherwise force the coppers together across the mica insulation at the end of the commutator. This should be avoided if possible; but if it has to be done in an emergency, the crushed material can afterwards be picked out and the injury smoothed over. In carrying out any of these methods, great care should be taken not to short-circuit any other armature coil, which would cause sparking (Cause 5).

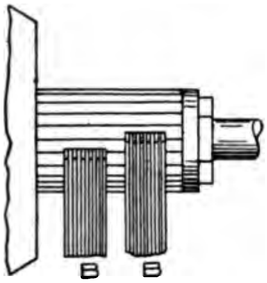

Fig. 62.

CAUSE 7. **Ground in Armature.**

SYMPTOM. Two "grounds" (accidental connections between the conductors on the armature and its iron core or the shaft or spider) would have practically the same effect as a short circuit (Cause 5), and would be treated in the same way. A single ground would have little or no effect, provided the circuit is not intentionally or accidentally grounded at some other point. On an electric-railway ("trolley") or other circuit employing the earth as a return conductor, one or more grounds in the armature would allow the current to pass directly through them, and would cause the motor to spark and have a variable torque at different parts of a revolution.

REMEDY. A ground can be detected by testing with a magneto bell (page 67). It can also be located by the drop-of-potential method (page 63). Another way to locate it is to wrap a wire around the commutator so as to make connection with all of the bars, and then connect a source of current to this wire and to the armature core (by pressing a wire upon the latter). The current will then flow from the armature conductors through the ground connection to the core, and the magnetic effect of the armature winding will be localized at the point where the ground is. This point is then found by the indications of a compass needle when slowly moved around the surface of the armature. The current may be obtained from a storage battery or from the circuit, but should be regulated by lamps or other resistance so as not to exceed the normal armature current. Sometimes the ground may be in a place where it can be corrected without much trouble, but usually the particular coil and often others must be rewound. A ground will be produced if the insulation is punctured by a spark of static electricity, which may be generated by the friction of the belt. If the frame of the machine is connected to the ground, the static charge will pass off to the ground; but such grounding is often inadvisable, and in such cases the frame may be connected to the ground through a Geissler tube, a wet thread, a heavy pencil-mark on a piece of unglazed porcelain, or other very high resistance which will carry off a static charge of very high potential and almost infinitesimal quantity, but will not permit the passage of any considerable current that might cause trouble.

CAUSE 8. **Weak Field Magnetism.**

SYMPTOM. Pole pieces not strongly magnetic when tested with a piece of iron. Point of least sparking is shifted considerably from normal position, owing to relatively strong distorting effect of armature magnetism. Speed of a shunt motor is usually high unless magnetism is very weak or *nil*, in which case a motor may run slow, stop, or even run backwards.* A generator fails to generate the full E.M.F. or current.

The particular cause of trouble may be found as follows: A broken circuit in the field of a motor is found by purposely opening the field circuit at some point, taking care first to disconnect armature (by putting wood under the brushes, for example), and to use only one hand, to avoid shock. If there is no spark when circuit is thus opened, there must be a broken circuit somewhere. A short circuit in the field coils is found by measuring their resistance roughly to see if it is very much less than it should be. Usually a short circuit is confined to one magnet, and will therefore weaken that one more than the others; and a piece of iron held half-way between the pole pieces will be attracted to one more than to the other. The short circuit may be found by the drop-of-potential method, by testing from the joint between the field coils to each outside terminal. "Grounding" is practically identical with short-circuiting, but one ground will not produce this effect until another occurs. A double ground, through which the current finds a complete path, is equivalent to a short circuit. In the ordinary "trolley" electric-railway system, a ground return is used, and the neutral conductor of three-wire systems is often grounded. In such cases one ground may be sufficient to cut out one or more field coils.

If one field coil is reversed and opposed to the others, it will weaken the field magnetism and cause bad sparking. This may be detected by examining the field coils to see if they are all connected in the right way, or by testing with a compass needle. (See IX, 4.) The series-coil of a compound-wound dynamo or motor is ofted connected wrongly, and will have the wrong effect, that is, will reduce the voltage of the former or raise the speed of the latter with increase of load.

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* **NOTE. If the motor is not loaded, it will race.**

REMEDY. A broken or short circuit or a ground is easily repaired if external or accessible. If it is internal, the only remedy is to replace or rewind the faulty coil. A shunt motor will spark badly in starting if the armature is connected before the field. This can be remedied by adjusting the contacts and switch-arm. If the voltage is too low on the circuit, it may cause sparking in a shunt dynamo or motor; and if the voltage cannot be raised, the resistance of the field circuit should be reduced by unwinding a few layers of wire or by substituting other coils (See VII, VIII, IX, and X.)

CAUSE 9. **Vibration of Machine.**

SYMPTOM. Considerable vibration is felt when the hand is placed upon the machine, and sparking decreases if the vibration is reduced.

REMEDY. The vibration is usually due to an imperfectly balanced armature or pulley (see VI, 1), to a bad belt (see VI, 6), or to unsteady foundations; and the remedies described for these troubles should be applied.

Any considerable vibration is likely to produce sparking, of which it is a common cause. This sparking can be reduced by increasing the pressure of the brushes on the commutator, but the vibration itself should be overcome.

CAUSE 10. **Chatter of Brushes.**

The commutator sometimes becomes sticky when carbon brushes are used, causing friction, which throws the brushes into rapid vibration as the commutator revolves, similar to the action of a violin bow.

SYMPTOM. Slight tingling or jarring is felt in brushes.

REMEDY. Clean commutator, and oil slightly.

CAUSE 11. **Flying break in armature conductor.**

SYMPTOM. No break found by test with armature standing still, but break shown by flashing at brushes, when running, being usually due to centrifugal force.

REMEDY. Tighten connections to commutator, or repair broken wire, etc.

EXCESSIVE HEATING IN GENERATOR OR MOTOR.

General Instructions. The degree of heat that is injurious or objectionable in a generator or motor is easily determined by feeling the various parts. If the heat is bearable to the hand, it is entirely harmless; but if unbearable, the safe limit of temperature has been approached or passed, and the heat should be reduced in some of the ways that are indicated below. In testing with the hand, allowance should be made for the fact that bare metal feels much hotter than cotton at the same temperature. The back of the hand is more sensitive than the palm for this test. If the heat has become so great as to produce an odor or smoke, the safe limit has been far exceeded, and the current should be shut off immediately and the machine stopped, as this indicates a serious trouble, such as a short-circuited coil or tight bearing. The machine should not again be started until the cause of the trouble has been found and positively overcome. Of course, neither water nor ice should ever be used to cool electrical machinery, except possibly the bearings of large machines at points where they can be applied without danger of wetting the other parts.

Feeling for heat will serve as a rough test to detect excessive temperatures or in emergencies; but, of course, the sensitiveness of the hand varies, and it makes a great difference whether the surface is a good or bad conductor of heat. The proper and reliable methods for determining rise in temperature are given on page 59, Part I.

It is very important, in all cases of heating, to locate the source of heat in the exact part in which it is produced. It is a common mistake to suppose that any part of a machine that is found to be hot is the seat of the trouble. A hot bearing may cause the armature or commutator to heat, or *vice versa*. In every case all parts of the machine should be tried to find which is the hottest, since heat generated in one part is rapidly diffused throughout the entire machine. It is better to make observations for heating by starting with the whole machine cool, which is done by letting it stand for several hours.

II. HEATING OF COMMUTATOR AND BRUSHES.

Cause 1. **Heat spread from another part of machine.**

Symptom. Start with the machine cool, and run for a short time, so that heat will not have time to spread. The real seat of trouble is the part that heats first.

Remedy. (See Heating of Armature, Fields, and Bearings.)

CAUSE 2. **Sparking.** Any of the causes of sparking will cause heating, which may be slight or serious.

SYMPTOM and REMEDY. See "Sparking."

CAUSE 3. **Tendency to spark, or slight sparking hardly visible.**

Sometimes before sparking appears, serious heating is produced by the causes of sparking, such as the short-circuiting of the coils as their commutator-bars pass under the brushes.

SYMPTOM. Reduced by applying the principal remedies for sparking, such as slightly shifting rocker-arm. Fine sparks may be found by sighting in exact line with the surface of contact between the commutator and brushes.

REMEDY. (See "Sparking.") Apply the remedies with extra care. This incipient sparking may be due to excessive inductance in the armature coils, which can be corrected only by reconstruction; or it may be due to insufficient field strength, and this can be cured by increasing the ampere-turns of field winding.

CAUSE 4. **Overheated commutator will decompose carbon brush.**

The effect is to cover commutator with a black film which offers resistance and aggravates the heat.

SYMPTOM. Commutator covered with dark coating; commutator, brushes and holders show marks of abnormal heat.

REMEDY. Commutator and brushes should be carefully cleaned, and the latter adjusted to make good contact at the proper points.

CAUSE 5. **Bad connections in brush-holder, cable, etc.**

SYMPTOM. Holder, cable, etc., feel hottest; unusual resistance found in these parts by "drop method."

REMEDY. Improve the connections.

CAUSE 6. **Arcing or short circuit in commutator.**

This may occur across mica or insulation between bars or nuts.

SYMPTOM. Burnt spot between parts; spark appears in the insulation when current is put on.

REMEDY. Pick out the charred particles; take commutator apart and repair; or put on new commutator.

CAUSE 7. **Carbon brushes heated by the current.**

Carbon brushes require less attention than copper, because they do not cut the commutator, and their resistance usually reduces sparking, but it may also cause them to heat.

SYMPTOM. Brushes hotter than other parts.

REMEDY. Use carbon of higher conductivity. Let the brush-holder grip brush closer to commutator, so as to reduce the length of brush through which the current must pass. Reinforce the brush with copper gauze or sheet copper. Use larger brushes or a greater number.

III. HEATING OF ARMATURE.

CAUSE 1. **Excessive current in armature coils.**

SYMPTOM and REMEDY the same as in case of "Sparking," Cause 1.

CAUSE 2. **Short-circuited armature coils.**

SYMPTOM and REMEDY the same as in case of "Sparking;" Cause 5. See also Cause 7.

CAUSE 3. **Moisture in armature coils.**

SYMPTOM. Armature requires considerable power to run free. Armature steams when hot, or feels moist. This is really a special case of Cause 2, as moisture has the effect of short-circuiting the coils through the insulation. Measure insulation resistance of armature ; this should test at least one megohm if armature is in good condition, but would be much lowered by moisture. (See "Insulation Tests.")

REMEDY. The armature should be baked for 5 to 10 hours in an oven or other place sufficiently warm to drive out the moisture, but not hot enough to run any risk of burning or even slightly charring the insulation. A neat way to do this is to pass through the armature a current regulated to be about three quarters of the rated armature current, the armature being held still or turned over occasionally.

CAUSE 4. **Foucault currents in armature core.**

SYMPTOM. Iron of armature core hotter than coils after a short run, and considerable power required to run armature when

NOTE. Any excess of current taken by an armature when running *free*, whatever the cause, must be converted into heat by some defect in the motor; hence the "free current" is the simplest and most complete test of the efficiency and perfect condition of the machine.

field is magnetized and there is no load on armature. This can be distinguished from Cause 2 by absence of sparking and absence of excessive heat in a particular coil or coils after a short run. (See "Stray Power Tests.")

Remedy. Armature core should be laminated more perfectly, which is a matter of first construction.

Cause 5. **One or more reversed coils on one side of armature.** This will cause a local current to circulate around armature.

Symptom. Excessive current when running free, but no particular coil heated more than others. If a moderate current is applied to each coil in succession by touching wires carrying current to each two adjacent commutator-bars, a compass needle held over the coils will behave differently when the reversed coil is reached. In a motor the half of armature containing the reversed coils is heated more than the other.

Remedy. Reconnect the coil to agree with the others.

Cause 6. **Heat conveyed from other parts.**

Symptom. Other parts hotter than armature. Start with machine cool, and see if other parts heat first.

Remedy. See Heating of Bearings, Field and Commutator.

Cause 7. **Flying cross in armature conductor.**

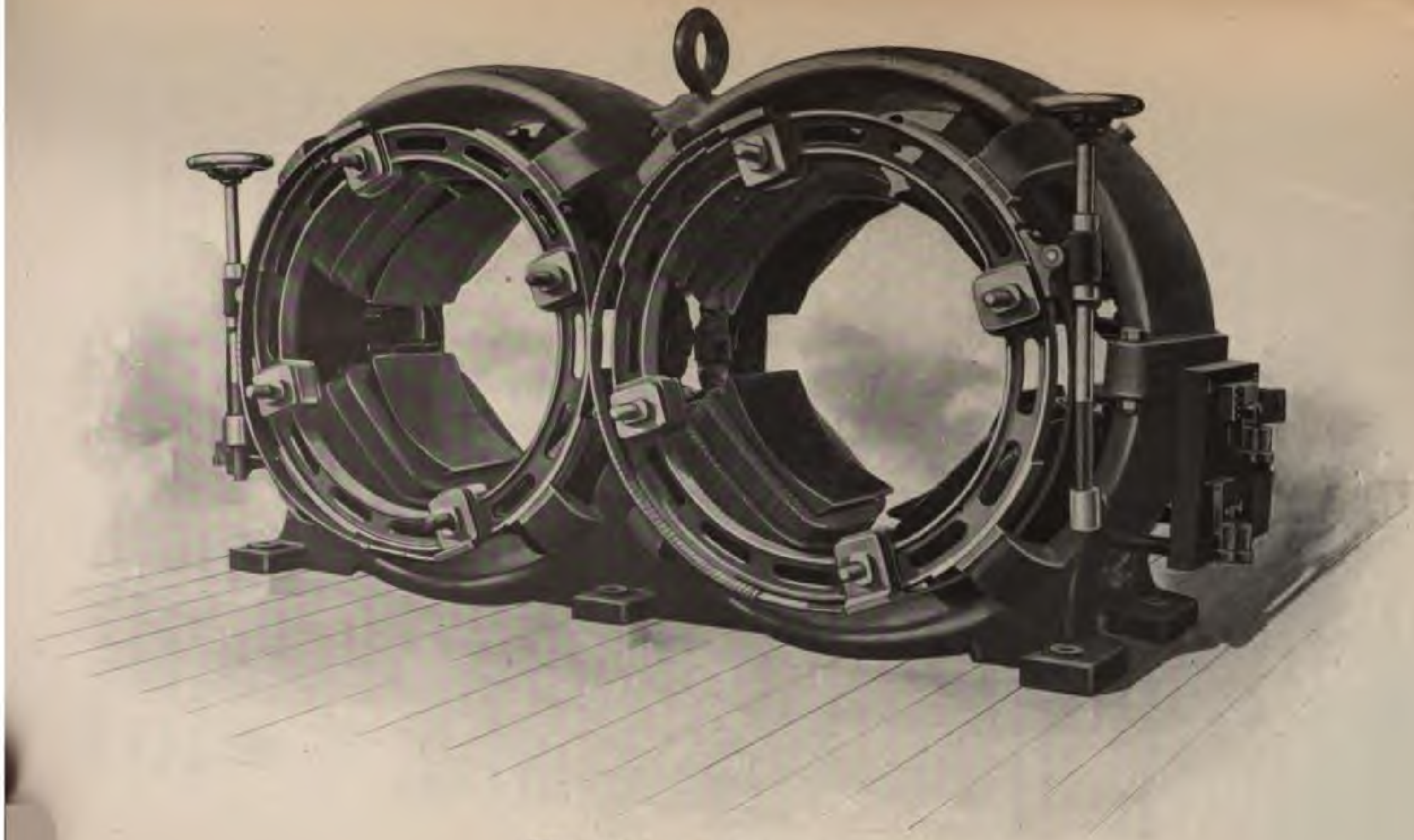
Symptom and Remedy similar to the case of sparking (Cause 11), except that reference here is to the insulation of the conductors.

IV. HEATING OF FIELD MAGNETS.

Cause 1. **Excessive current in field circuit.**

Symptom. Field coils too hot to keep the hand on. Their temperature more than 50°C above that of room by resistance test or by thermometer.

Remedy. In the case of a shunt-wound machine, decrease the voltage at terminals of field coils; or increase the resistance in field circuit by winding on more wire or putting resistance in series. In the case of a series-wound machine, shunt a portion of, or otherwise decrease, the current passing through field; or take a layer or more of wire off the field coils; or rewind with coarser wire. This trouble might be due to a short circuit in field coils in the case of a shunt-wound dynamo or motor, and would be indicated by the



FIELD FRAME 200 K.W., D.C. GENERATOR.

De Laval Steam Turbine Co.

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TILDEN FOUNDATIONS

pole piece with the short-circuited coil being weaker than the others. This coil is cooler than the others; in fact, if completely short-circuited, it is not heated at all. This condition can be remedied only by rewinding the short-circuited coil. Measure resistance of the field coils to see if they are nearly equal. (See "drop method.") If the difference is considerable (say, more than 5 or 10 per cent), it is almost a sure sign that one coil is short-circuited or double-grounded.

Cause 2. **Foucault currents in pole pieces or field cores.**

Symptom. The pole pieces hotter than the coils after a short run. When making the comparison, it is necessary to keep the hand on the coils some time before the full effect is reached, because the coils are insulated and the pole pieces are bare metal, and even then the coils will not feel so hot, although their actual temperature may be higher if measured by a thermometer.

Remedy. This trouble is due to faulty design of toothed-armature machines, which can be corrected only by rebuilding, or is caused by fluctuations in the current. The latter can be detected, if the variations are not too rapid, by putting an ammeter in circuit; or rapid variations may be felt by holding a piece of iron near the pole pieces, and noting whether it vibrates. In the case of an alternating current it is necessary to use laminated fields to avoid great heating.

Cause 3. **Moisture in field coils.**

Symptom. The field circuit tests lower in resistance than normal in that type of machine; and in the case of shunt-wound machines, the field takes more than the ordinary current. Field coils steam when hot, or feel moist to hand. The insulation resistance also tests low.

Remedy. The same as for moisture in armature (III, 3).

V. HEATING OF BEARINGS.

The cause should be found and removed promptly, but heating of the bearings can be reduced temporarily by applying cold water or ice to them. This is allowable only when absolutely necessary to keep running; and great care should be taken not to allow any water to get upon the commutator, armature, or field-coils, as it might short-circuit or ground them. If the bearing is very hot, the shaft should be kept revolving slowly, as it might "freeze," or stick fast, if stopped entirely.

CAUSE 1. **Lack of oil.**

SYMPTOM. Oil-cup reservoir empty. Oil passages clogged. Self-oiling rings stick fast. Shaft and bearing look dry. The shaft does not turn freely.

REMEDY. Supply oil, and make sure that oil passages as well as feeding or self-oiling devices work freely, and that the oil cannot leak out. This last fault sometimes causes oil to fail sooner than attendant expects. A good quality of oil should always be used, as poor oil might be as bad as no oil.

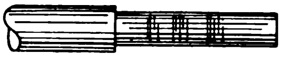

Fig. 63.

CAUSE 2. **Grit or other foreign matter in bearings.**

SYMPTOM. Best detected by removing shaft or bearing and examining both. Any grit can of course be felt easily, and will also cut the shaft.

REMEDY. Remove shaft or bearing, clean both very carefully, and see that no grit can get in. Place machine in dustless place or box it in. The oil should be perfectly clean; if not, it should be filtered. If it is not possible to stop the machine or to remove the shaft, the dirt may be washed out with kerosene or water; but these should not be allowed to get on the commutator, armature, or field coils.

CAUSE 3. **Shaft rough or cut.** (Fig. 63.)

SYMPTOM. Shaft will show grooves or roughness, and will probably revolve stiffly.

REMEDY. Turn shaft in lathe; or smooth with fine file; and see that bearing is smooth and fits shaft.

CAUSE 4. **Shaft and bearing fit too tight.**

SYMPTOM. Shaft hard to revolve by hand.

REMEDY. Turn or file down shaft in lathe, or scrape or ream out bearings.

CAUSE 5. **Shaft "sprung" or bent.**

SYMPTOM. Shaft hard to revolve, and usually sticks much more in one part of revolution than in another.

REMEDY. It is very difficult to straighten a bent shaft. It might be bent back or turned true, but probably a new shaft will be necessary.

CAUSE 6. **Bearings out of line.**

SYMPTOM. Shaft hard to revolve, but is much relieved by slightly loosening the screws that hold bearings in place, when machine is not running and when belt, if any, is taken off.

REMEDY. Loosen the bearings by partly unscrewing bolts or screws holding them in place, and find their easy and true position, which may require one of them to be moved either sideways or up or down; then file the screw-holes of that bearing, or raise or lower it, as may be necessary, to make it occupy the right position when the screws are tightened. The armature, however, must be kept in the center of the space between the pole pieces, so that the clearance is uniform all around. (See Cause 9.)

CAUSE 7. **Thrust or pressure of pulley, collar, or shoulder on shaft against one or both of the bearings.**

SYMPTOM. Move shaft back and forth with a stick applied to the end while revolving, and note if the collar or shoulder tends to be pushed or drawn against either bearing. It is usually desirable that a shaft should move freely back and forth about an eighth of an inch, to make commutator and bearings wear smoothly.

REMEDY. Line up the belt; shift collar or pulley; turn off shoulder on shaft, or file off bearing, until the shoulder does not touch when running, or until pressure is relieved.

CAUSE 8. **Too great a load or strain on the belt.**

SYMPTOM. Great tension on belt. In this case the pulley bearing will probably be very much hotter than the other, and also worn elliptical, as indicated in Fig. 64, in which case the shaft can be shaken in the bearing in the direction of the belt pull, when the belt is off, provided the machine has been running long enough to wear the bearings.

REMEDY. Reduce load or belt tension, or use larger pulleys and lighter belt, so as to relieve side strain on shaft. (See "Belting.")

CAUSE 9. **Armature too near one pole piece, producing much greater magnetic attraction on nearer side.**

SYMPTOM. Examine the clearance of armature to see if it is uniform on all sides. Charge and discharge the field magnet, the armature being disconnected (by putting wood under the brushes);

and note whether armature seems to be drawn to one side and turns very much less easily when field is magnetized.

REMEDY. This fault is due either to a defect in the original construction, or to wear in the bearings, either of which is difficult to correct; but in cases of necessity the armature can be centered exactly in the field by moving the bearings, which may be done by carefully filing the holes through which the screws pass that hold the bearings in place; or the pole piece may be filed away where it is too near the armature.

Trouble from this cause is greater in multipolar than in bipolar machines, and always tends to become aggravated, because the more the side pull the more the bearings wear in that direction. If, on the other hand, the armature is in the center of the space formed by the pole pieces, the magnetic pull is practically balanced in all directions.

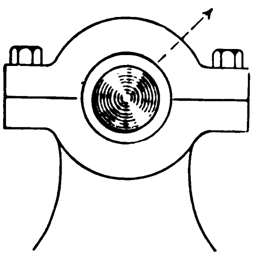

Fig. 64.

It is risky to file bolt-holes or make any such change in a machine; and this should never be attempted before consulting an experienced machinist. Very often the trouble is due to the parts being out of place merely because they have not been put together right or because there is dirt between them. If the bearing is worn, it may be rebabbitted or renewed.

CAUSE 10. **Bearing heated by hot pulley, commutator, or armature.**

SYMPTOM. Pulley, armature, or commutator hotter than bearing. The slipping of the belt on the pulley, sparking at the commutator, or heating of the armature may heat one or both bearings of the machine, in which case an examination will show that these parts are hotter than the bearing, and the real source of the trouble.

REMEDY. A slipping belt, sparking commutator, or hot armature can be cured as described under these headings, and then the bearing will probably cease to heat.

VI. NOISY OPERATION.

CAUSE 1. **Vibration due to armature or pulley being out of balance.**

SYMPTOM. Strong vibration felt when the hand is placed upon the machine while it is running. Vibration changes greatly if speed is changed, and sometimes almost disappears at certain speeds.

REMEDY. Armature or pulley must be perfectly balanced by securely attaching lead or other weight on the light side, or by drilling or filing away some of the metal on the heavy side. The easiest method of finding in which direction the armature is out of balance is to take it out, and to rest the shaft on two parallel and horizontal A-shaped metallic tracks sufficiently far apart to allow the armature to go between them (Fig. 65). If the armature is then slowly rolled back and forth, the heavy side will tend to turn downward. The armature and pulley should always be balanced separately. An excess of weight on one side of the pulley and an equal excess of weight on the opposite side of the armature will not produce a balance while running, though it does when standing still; on the contrary, it will give the shaft a strong tendency to "wobble." A perfect balance is obtained only when the weights are directly opposite, *i.e.*, in the same line perpendicular to the shaft.

CAUSE 2. **Armature strikes or rubs against pole pieces.**

SYMPTOM. Easily detected by placing the ear near the pole pieces; or by examining armature to see if its surface is abraded at any point; or by examining each part of the space between armature and field as armature is slowly revolved, to see if any portion of it touches or is so close as to be likely to touch when the machine is running. In small machines, the armature may be turned by hand, noting whether it sticks at any point.

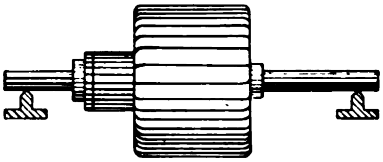

Fig. 65.

REMEDY. Bind down any wire or other part of the armature that may project abnormally; or file out the pole pieces where the armature strikes; or center the armature so that there is a uniform clearance between it and the pole pieces at all points.

CAUSE 3. **Shaft collar or shoulder, hub or edge of pulley, or belt, strikes or scrapes against bearings.**

Symptom. **Rattling noise, which stops when the shaft or pulley is pushed lengthwise away from one or the other of the bearings. (See "Heating of Bearings," Cause 7.)**

Remedy. **Shift the collar or pulley, turn off the shoulder on the shaft, file or turn off the bearing, move the pulley on the shaft, or straighten the belt, until there is no more striking, and the noise ceases.**

Cause 4. **Rattling due to looseness of screws or other parts.**

Symptom. Close examination of the bearings, shaft, pulley, screws, nuts, binding-posts, etc., or touching the machine while running, or shaking its parts while standing still, shows that some parts are loose.

Remedy. Tighten up the loose parts, and be careful to keep them all properly set up. It is easy to guard against the occurrence of this trouble, which is very common, by simply examining the various screws and other parts each day before the machine is started. Electrical machinery being usually high-speed, the parts are particularly liable to shake loose. A worn or poorly fitted bearing might allow the shaft to rattle and make a noise, in which case the bearing should be refitted or renewed.

Cause 5. **Singing or hissing of brushes.** This is usually occasioned by rough or sticky commutator (see "Sparking," Causes 3 and 10), or by brushes not being smooth, or by the layers of a copper brush not being held together and in place. With carbon brushes, hissing will be caused by the use of carbon that is gritty or too hard. Vertical carbon brushes, or brushes inclined against the direction of rotation, are liable to squeak or sing. Occasionally, a new machine will make noise that is reduced after the machine has been run for some time.

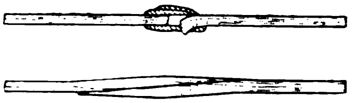

Fig. 66.

Symptom. Sound of high pitch, and easily located by placing the ear near the commutator while it is running, and by lifting off the brushes one at a time, provided there are two or more in each set, so that the circuit is not opened. If there is no current there is no objection to raising the brushes.

Remedy. Apply a *very little* oil or vaseline to the commutator with the finger or a rag. Adjust the brushes or smooth the commutator by turning or filing, or by using fine sandpaper, being careful to clean thoroughly afterwards. Carbon brushes are liable to squeak in starting up or at low speed. This decreases at full speed, and can generally be stopped by moistening the brushes with oil, care being taken not to have any drops or excess of oil. Shortening or lengthening the brushes sometimes stops the noise. Running the machine without load for some time usually reduces this trouble.

CAUSE 6. **Flapping or pounding of belt joint or lacing against pulley.** (Fig. 66.)

SYMPTOM. Sound repeated once for each complete revolution of the belt, which is much less frequent than any other generator or motor sound, and can easily be detected or counted.

REMEDY. Endless belt or smoother joint. (See "Belting.")

CAUSE 7. **Slipping of belt on pulley due to overload.**

SYMPTOM. Intermittent squeaking noise.

REMEDY. Tighten the belt or reduce the load. A wider belt or larger pulley may be required. Powdered rosin may be put on the belt to increase its adhesion ; but it is a makeshift, injurious to the belt, to be adopted only if necessary. (See "Belting.")

CAUSE 8. **Humming of armature-core teeth as they pass pole-pieces.**

SYMPTOM. Pure humming sound less metallic than Cause 5.

REMEDY. Slope or chamfer the ends of the pole pieces so that each armature tooth does not pass the edge of the pole piece all at once. Decrease the magnetization of the fields. Increase the air-gap or reduce the distance between the teeth. But these are nearly all matters of first construction and are made right by good manufacturers.

CAUSE 9. **Humming due to alternating or pulsating current.**

SYMPTOM This gives a sound similar to that in the preceding case. The two can be distinguished, if necessary, by determining whether the note given out corresponds to the number of alternations, or to the number of armature teeth passing per second.

Usually the latter is considerably greater than the former.

REMEDY. This trouble is confined to alternating apparatus, and its effects can be reduced by proper design and by mounting the machine so as to deaden the sound as far as possible.

It often happens that a generator or motor seems to make a noise, which in reality is caused by the engine or other machine with which it is connected. Careful listening with the ear close to the different parts will show exactly where the noise originates. A very sensitive method of locating a noise or vibration is to hold a short stick by one end between the teeth, and press the other end squarely against the several parts, to ascertain which particular one gives the greatest vibration.

VII. SPEED TOO HIGH OR TOO LOW.

This is generally a serious matter in either generator or motor, and it is always desirable and often imperative to shut down immediately, and make a careful investigation.

SPEED TOO LOW.

CAUSE 1. **Overload.** (See "Sparking," Cause 1.)

SYMPTOM. Armature runs more slowly than usual. Bad sparking at commutator. Ammeter indicates excessive current. Armature heats. Belt very tight on tension side.

REMEDY. Reduce the load on machine, decrease the diameter of driving pulley, or increase the diameter of driven pulley. If necessary to relieve strain of overload, temporarily decrease the voltage on either a generator or a motor.

CAUSE 2. **Short circuit or ground in armature.**

SYMPTOM and REMEDY the same as in case of "Heating of Armature, Cause 2 and Cause 6.

CAUSE 3. **Armature strikes pole pieces.**

SYMPTOM and REMEDY the same as in case of "Noise," Cause 2.

CAUSE 4. **Shaft does not revolve freely in the bearings.**

SYMPTOM and REMEDY the same as for "Heating of Bearings," all cases.

SPEED TOO HIGH OR TOO LOW.

CAUSE 5. **Field magnetism weak.**

This has the effect, on a constant-voltage circuit, of making a motor run too fast if lightly loaded, or too slow if heavily loaded, or even run backwards if the field magnet is not excited at all, as, for example, when the field circuit is broken. It makes a generator fail to "build up" or excite its field, or give the proper voltage in any case.

SYMPTOM and REMEDY the same as in case of "Sparking," Cause 8. (See the following Cause; also "Dynamo Fails to Generate ')

CAUSE 6. **Too high or too low voltage on the circuit.**

SYMPTOM. This would cause a motor to run too fast or too slow, respectively. It can be shown by measuring the voltage of the circuit.

REMEDY. The central station or generating plant should be notified that voltage is not right.

SPEED TOO HIGH.

CAUSE 7. **Motor too lightly loaded.**

SYMPTOM. A series-wound motor on a constant-potential circuit runs too fast, and may speed up to the bursting point if the load is very much reduced or removed entirely (by the breaking of the belt, for example).

REMEDY. Care should be exercised in using a series motor on a constant-potential circuit, except where the load is a fan, pump, or other machine that is *positively* connected or geared to the motor so that there is no danger of its being taken off. A shunt motor should be used if the load is likely to be thrown off.

VIII. MOTOR STOPS OR FAILS TO START.

This is an extreme case of the previous class ("Speed Too High or Too Low"), but is separated because it is more definite and permits of quicker diagnosis and treatment. This heading does not, of course, apply to generators, since any trouble in setting these in motion is usually outside of the machine itself.

CAUSE 1. **Great overload.**

A slight overload causes motor to run slowly, but an extreme overload will, of course, stop it entirely or "stall" it. (See "Sparking," Cause 1.)

SYMPTOM. On a constant-potential circuit the current is excessive, and safety-fuse blows or circuit-breaker opens. In their absence or failure, armature is burnt out.

REMEDY. Turn off switch instantly, reduce or take off th load, replace the fuse or circuit-breaker, if necessary, and turn on current again just long enough to see if trouble still exists; if so, take off more load.

CAUSE 2. **Very excessive friction due to shaft, bearings, or other parts being jammed, or armature touching pole pieces.**

SYMPTOM. Similar to previous case, but distinguished from it by the fact that the armature is hard to turn even when load is taken off. Examination shows that the shaft is too large or is bent or rough, that the bearing is too tight, that the armature touches pole pieces, or that there is some other impediment to free rotation. (See "Heating of Bearings" and "Noise.")

REMEDY. Turn current off instantly, ascertain and remove the cause of friction, turn on the current again just long enough to see if trouble still exists; if so, investigate further.

CAUSE 3. **Circuit open.**

This may be due to (*a*) safety-fuse blown or circuit-breaker open; (*b*) wire in motor broken or slipped out of connections; (*c*) brushes not in contact with commutator; (*d*) switch open; (*e*) circuit supplying motor open; (*f*) failure at generating plant.

SYMPTOM. Distinguished from causes 1 and 2 by the fact that if the load is taken off, the motor still refuses to start, and yet armature turns freely.

On a constant-potential circuit the field circuit alone of a shunt motor may be open, in which case the pole pieces are not strongly magnetic when tested with a piece of iron, and there is a dangerously heavy current in the armature; if the armature circuit is at fault, there is no spark when the brushes are lifted; and if both are without current, there is no spark when switch is opened. One should be very careful if there is no field magnetism or even if it is weak, as a motor is liable to be burnt out if the current is then thrown upon the armature.

REMEDY. Turn current off instantly. Examine safety-fuse circuit-breaker, wires, brushes, switch, and circuit generally, for break or fault. If none can be found, turn on switch again for a moment, as the trouble may have been due to a temporary stoppage of the current at the station or on the line. If motor still seems dead, test separately armature, field coils, and other parts of circuit for continuity with a magneto or a cell of battery and an electric bell, to see if there is any break in the circuit. (See "Instructions for Testing.")

One of the simplest ways to find whether the circuit has current on it and to locate any break, is to test through an incandescent lamp. Two or five lamps in series should be used on 220- and 500-volt circuits, respectively.

CAUSE 4. **Wrong connection or complete short circuit of field, armature, switch, etc.**

SYMPTOM. Distinguished from Causes 1 and 2 in the same way as Cause 3, and differs from Cause 3 in the evidence of strong current in motor.

On a constant-potential circuit, if current is very great, it indicates a short circuit. If the field is at fault, it will not be strongly magnetic.

The possible complications of wrong connections are so great that no exact rules can be given. Carefully examine and make sure of the correctness of all connections (see Diagrams of Connections). This trouble is usually inexcusable, since only a competent person should ever set up a machine or change its connections.

In the 3-wire (220-volt direct-current) system, several peculiar conditions may exist, as follows:

(*a*) The dynamo or dynamos on one side of the system may become reversed, so that both of the outside wires are positive or negative. In that case a motor fed in the usual way from the two outside conductors will get no current, but lamps connected between the neutral wire and either of the outside wires will burn as usual.

(*b*) If one of the outside wires is open by the blowing of a fuse, an accidental break, or other cause, then a motor (220-volt) beyond the break can get some current at 110 volts through any lamps that may be on the same side of the break as itself, and on the same side of the system as the conductor that is open. These lamps will light up when the motor is connected, but the motor will have little or no power unless the number of lamps is large.

(*c*) If the neutral or middle wire is open, a motor connected with the outside wires will run as usual; but lamps on one side of the system will burn more brightly than those on the other side, unless the two sides are perfectly balanced.

(*d*) If one of the outside wires becomes accidentally grounded, a 110-volt dynamo, motor, or other apparatus, also grounded and connected to the other outside wire, will receive 220 volts, which will probably burn it out.

IX. DYNAMO FAILS TO GENERATE.

This trouble is almost always caused by the inability of a dynamo to "excite" or "build up" its field-magnetism sufficiently. The proper starting of a self-exciting dynamo requires a certain amount of residual magnetism, which must be increased to full strength by the current generated in the machine itself. This trouble is not likely to occur in a separately-excited machine; and if it does it is usually due to the exciter failing to generate, and therefore amounts to the same thing.

CAUSE 1. **Residual magnetism too weak or destroyed.**

This may be due to (*a*) vibration or jar; (*b*) proximity of another dynamo; (*c*) earth's magnetism; (*d*) accidental reversed current through fields, not enough to completely reverse magnetism. The complete reversal of the residual magnetism in any dynamo will not prevent its generating, but will only make it build up of opposite polarity. Sometimes reversal of residual magnetism may be very objectionable, as in case of charging storage batteries; but, although the popular supposition is to the contrary, it will not cause the machine to fail to generate.

SYMPTOM. Little or no magnetic attraction when the pole pieces are tested with a piece of iron.

REMEDY. Send a magnetizing current from another machine or battery through the field coils, then start and try the machine; if this fails, apply the current in the opposite direction, since the magnets may have enough polarity to prevent the battery building them up in the direction first tried.

Shift the brushes forward in a generator, or backward in a motor to make armature magnetism assist field. Turn machine around or change its polarity, so that the magnetism which the earth or the adjacent machine tends to induce is in the right direction. Dynamos should be placed with their opposite poles toward each other, and the north pole of a machine should preferably be placed toward the north (which is magnetically the *south* pole of the earth); but the earth's magnetism is hardly strong enough to reverse a dynamo's residual magnetism.

CAUSE 2. **Reversed connections or reverse direction of rotation.**

SYMPTOM. When running, pole pieces show no attraction for a piece of iron. The application of external current cannot be made to start the machine, as in case of Cause 1, because, whichever way the field may be magnetized, the resulting current generated by armature opposes and destroys the magnetism.

REMEDY. (*a*) Reverse either armature connections or field connections, *but not both.* (*b*) Move brushes through 180° for 2-pole, 90° for 4-pole machines, etc. (*c*) Reverse direction of rotation. After each of the above are tried, the field may have to be built up with a battery or other current, since the causes in this case operate to destroy whatever residual magnetism may have been present.

CAUSE 3. **Short circuit in the machine or external circuit.**

This applies to a shunt-wound machine, and has the effect of preventing the voltage and the field magnetism from building up.

SYMPTOM. Magnetism weak, but still quite perceptible.

REMEDY. If the short circuit is in the external circuit, opening the latter will allow the dynamo to build up and generate full voltage. If the short circuit is within the machine, it should be found by careful inspection or testing. In either of these cases, do not connect the external circuit until short circuit is found and eliminated. A slight short curcuit, such as that caused by a defective lamp socket or by copper dust on the brush-holder or commutator, may prevent the magnetism of a shunt machine from building up. (See "Sparking," Causes 5 and 8.) Too many lamps, or other load, might prevent a shunt dynamo from building up its field magnetism, in which case the load should be disconnected in starting.

CAUSE 4. **Field-coils opposed to each other.**

SYMPTOM. Upon passing a current from another dynamo of a battery the following symptom will exist: If the pole-pieces of a bipolar machine are approached with a compass or other freely suspended magnet, they both attract the same end of the magnet, showing them to be of the same polarity, whereas they should always be of opposite polarity.

For similar reasons the pole-pieces are magnetic when tested separately with a piece of iron, but show less attraction when the same piece of iron is applied to both at once, in which latter case the attraction should be stronger. In multipolar machines these tests should be applied to consecutive pole-pieces.

REMEDY. Reverse the connections of one of the coils in order to make the polarity of the pole-pieces opposite. The pole-pieces should be alternately north and south (when tested by compass).

CAUSE 5. **Open circuit.**

This may be due to (*a*) broken wire or faulty connection in machine; (*b*) brushes not in contact with commutator; (*c*) safety fuse melted or absent; (*d*) switch open; (*e*) external circuit open.

SYMPTOM. If the trouble is merely due to the switch or external circuit being open, the magnetism of a shunt dynamo may be at full strength, and the machine itself may be working perfectly; but if the trouble is in the machine, the field magnetism will probably be very weak.

REMEDY. Make very careful examination for open circuit; if not found, test separately the field-coils, armature, etc., for continuity, with magneto or cell of battery and electric bell. (See "Instructions for Testing;" also "Motor Stops," etc., Cause 3.)

A break, poor contact, or excessive resistance in the field circuit or regulator of a shunt dynamo will also make the magnetism weak and prevent its building up. This may be detected and overcome by cutting out the rheostat for a moment by connecting the two terminals of the field-coils to the two brushes respectively, care being taken not to make a short circuit.

A break or abnormally high resistance anywhere in the circuit of a series-wound dynamo will prevent it from generating, since the field-coil is in the main circuit. This may be detected and overcome by short-circuiting the machine for a moment in order to start up the magnetism.

Either of these two remedies by short-circuiting should be applied very carefully, and not until the pole-pieces have been tested with a piece of iron to make sure that the magnetism is weak.

Cause 6. **Brushes not in proper position.**

Symptom. The magnetism and current are increased by shifting the brushes.

Remedy. It often happens that the brushes are not set at the proper point; in fact, they may be set exactly wrong, so that the dynamo is incapable of generating any current whatever. This trouble is mainly due to the fact that the proper position for the brushes is not the same for all kinds of machines. Almost all ring armatures and many drum armatures require the brushes to be set opposite the *spaces* between the pole-pieces. But most armatures are wound so that the brushes must be set nearly 90° from this position, or opposite the center of the poles. Some multipolar machines have as many sets of brushes as there are pole pieces; while others have armatures that are cross-connected, or have the conductors arranged in series so that only two sets of brushes are required. Four-pole machines with only two brushes require them to be set at 90°; 6-pole machines, either 60° or 180°; 8-pole, either 45° or 135°; 10-pole, either 36°, 108°, or 180°; 12-pole, either 30°, 90°, or 130°; and 16-pole, either 22½°, 67½°, 112°, or 157½°; and so on.

The fact is, that the proper position of the brushes depends upon the particular winding, internal connections, etc., and *no one should ever assume to know where to set the brushes* unless he is perfectly familiar with the particular type of machine. A blue print or other definite instructions should always be obtained and followed; and, if these are not available, the matter may be determined by careful trial. The proper position of brushes is the same for dynamos and motors, except that in the former the brushes are given a forward lead, that is, shifted a little in the direction of rotation, whereas motor brushes should be set a little backward. This shifting is necessitated by the armature reaction or the magnetizing effect of the armature current, which distorts the field magnetism.

The positions and number of brushes for each kind of armature are show in Fig. 67, which shows also the *arrangements of circuits* in each of the leading types.

A is the armature for the ordinary two-pole machine, and may be drum- or ring-wound. The current enters from the positive

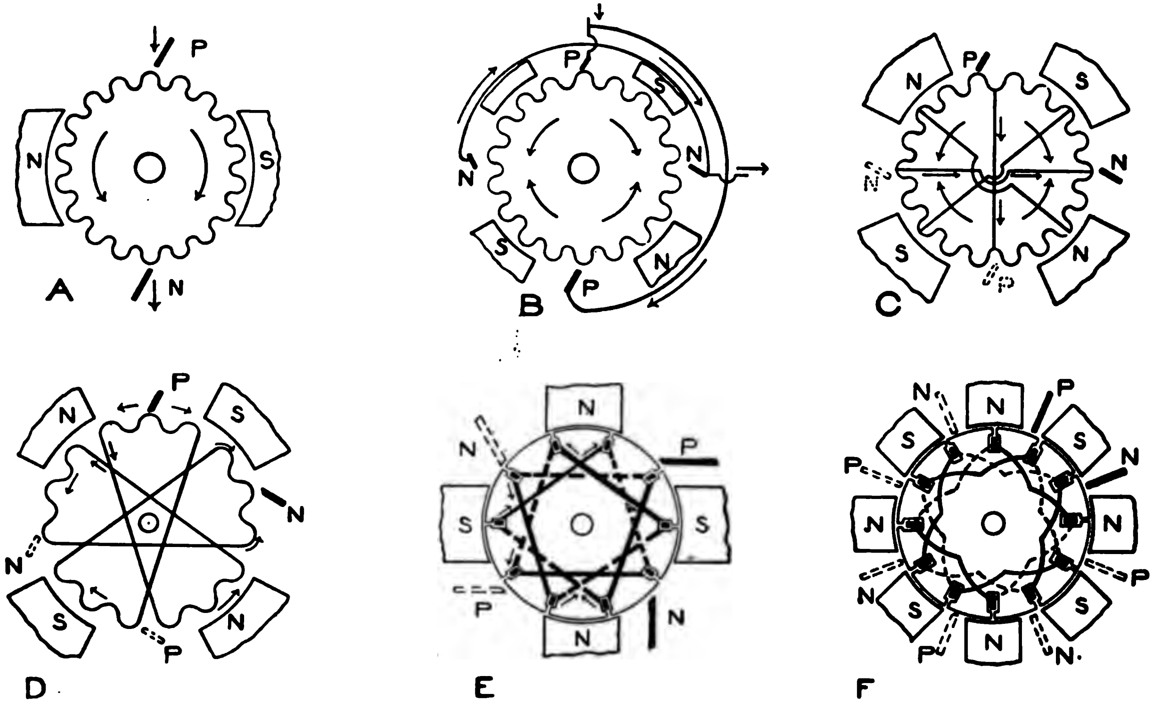

Fig. 67.

A = Two Pole, Two Circuit.
B = Four Pole, Four Circuit, Four Brushes in Multiple.
C = Four Pole, Four Circuit, Cross Connected, Two or Four Brushes in Multiple.
D = Four Pole, Two Circuit Ring, Two or Four Brushes in Multiple.
E = Four Pole, Two Circuit Drum, Two or Four Brushes in Multiple.
F = Eight Pole, Two Circuit Drum, Two, Four, Six, or Eight Brushes in Multiple.

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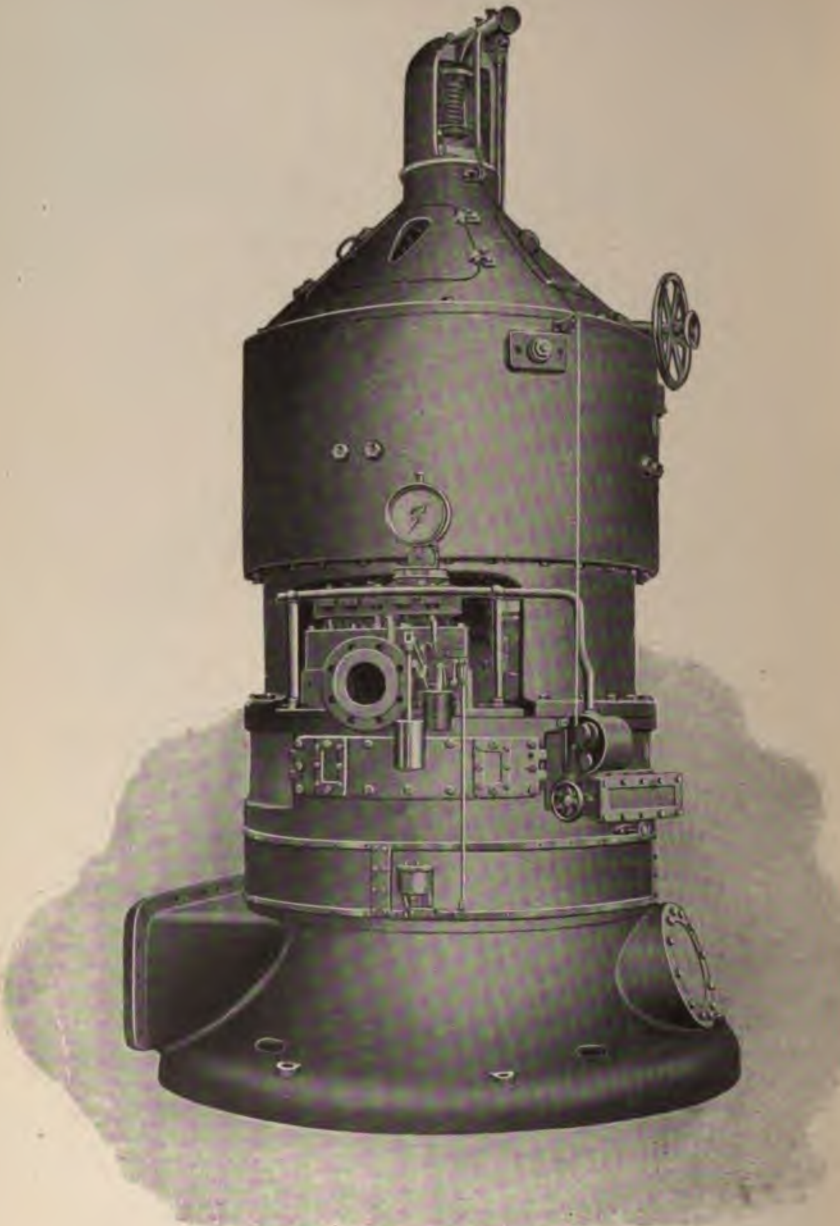


500 Kw. CURTIS STEAM TURBINE.
Direct Connected to Continuous Current Generator.

brush, passes around both sides of the armature, and out through the negative brush. Hence this is called a "two-circuit" armature.

B is a plain armature used in a 4-pole machine. As there are here two more poles, it is necessary to use two more brushes to collect the current. This gives two brushes through which current enters, and two through which it leaves; consequently each pair of brushes must be joined in multiple in order to carry all the current to the mains.

C is a 4-pole armature in which the additional currents are carried across to the first pair of brushes by means of connections through the center of the armature. Therefore, the entire current may be taken off by these brushes; or two more may be added to divide the work, in which case they must also be connected in multiple to the first pair, as in case B above.

With either B or C, since there are two parts of the armature winding under the influence of different magnets, but running in parallel to the mains, it is evident that if the pressure of the current in one part of the winding is weaker than in the other, through inequality of the magnets or otherwise, it will short-circuit the other part of the winding and work badly.

This cannot occur in A, because both parts of the winding are influenced by the two ends of a single magnet.

D is a 4-pole armature in which the windings do not connect together in parallel but *in series*, thus overcoming the objection above. It has a ring-winding, and each coil is connected to the one diametrically opposite. An examination will show that though the poles alternate, the wire is all arranged so that the current flows in a single pair of circuits, as in A. This also permits of the use of larger wire and fewer turns, as they are connected in series instead of multiple.

E is a drum armature all in series, as in the case of D. Inspection will show that the actions of each of the four poles on all the bars harmonize, or cause the current to flow in the same direction.

To facilitate tracing the course of the current, the arrangement is represented with the smallest possible number of bars. Many more are used in practice.

F is a series drum armature for eight poles. The principle is the same, but the limit of brush adjustment is smaller. The entire range from zero to full E. M. F. is covered by moving the brush one-eighth of the circumference.

As the winding is all in series, two brushes only are necessary; but as many more as desired may be added between the other poles, and then connected in multiple to the first ones. This is usually taken advantage of, because a single pair of brushes would become heated from carrying excessive current; but the difficulty of one part of the armature short-circuiting the other cannot occur, because *each part* of the winding is under the influence of all the poles.

X. VOLTAGE OF GENERATOR NOT RIGHT

VOLTAGE TOO LOW.

CAUSE 1. **Speed too low.** (See "Speed not Right.")

REMEDY. Increase speed of the prime mover, if possible; when this cannot be done, decrease the diameter of the driven pulley or increase the diameter of the driving pulley, preferably the latter.

CAUSE 2. **Field magnetism weak.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 8.)

CAUSE 3. **Brushes not in proper position.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 2.)

CAUSE 4. **Machine overloaded.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 1 and "Speed not Right," Cause 1); also increase field excitation, if possible.

CAUSE 5. **Short-circuited armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

CAUSE 6. **Reversed armature coil or coils.**

SYMPTOM AND REMEDY. (See "Sparking," Cause 5.)

VOLTAGE TOO HIGH.

CAUSE 7. **Speed too high.**

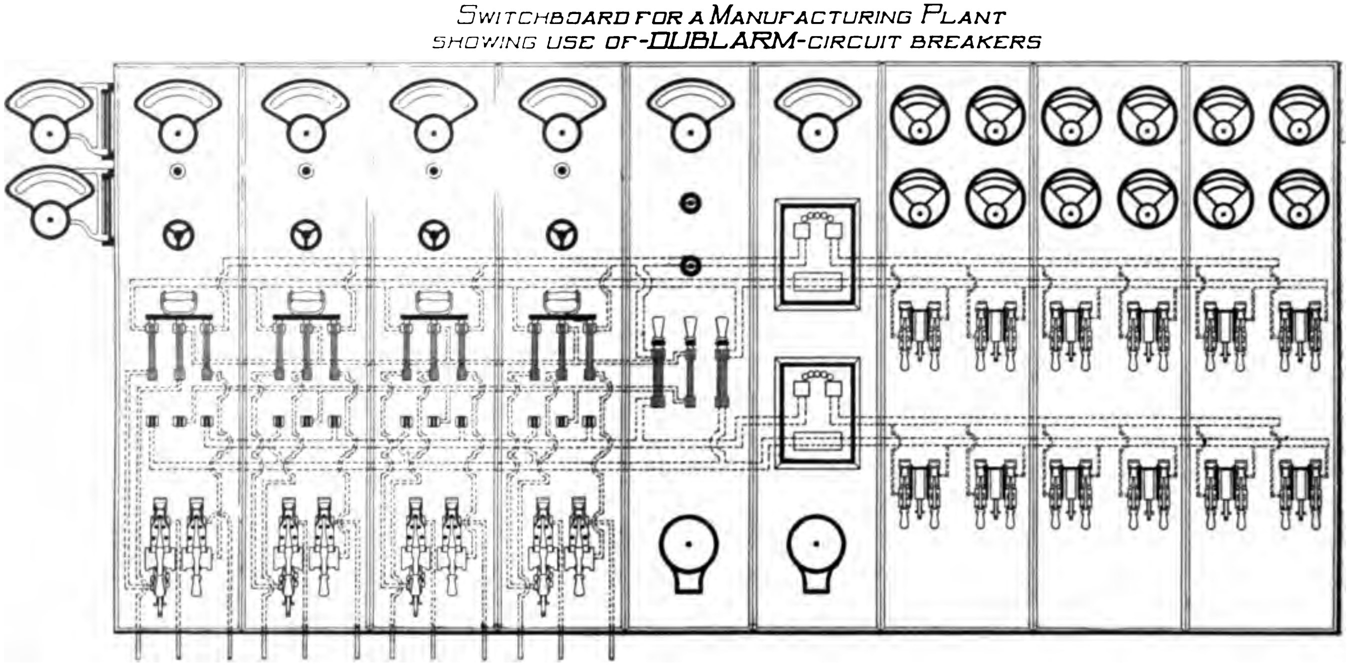
REMEDY. Apply the reverse of treatment given in Cause 1.

CAUSE 8 **Field magnetism too powerful.**

REMEDY. Increase resistance of shunt field circuit, by means of a shunt field rheostat.

CAUSE 9. **Machine Compounds too much.**

REMEDY. Decrease resistance of series field shunt. (See Compound-wound Dynamos, page 25, Part I.)


SWITCHBOARD FOR A MANUFACTURING PLANT
SHOWING USE OF -DUBLARM- CIRCUIT BREAKERS

SWITCHBOARD.

The Cutter Company.

POWER STATIONS.

With the rapid increase of the use of electricity for power, lighting, traction, and electro-chemical processes, the power houses equipped for the generation of the electrical supply have increased in size from plants containing a few low-capacity dynamos, belted to their prime movers and lighting a limited district, to the modern central station, furnishing power to immense systems and over extended areas. Examples of the latter type of station are found at Niagara Falls, such stations as the Metropolitan and Manhattan stations in New York City, the plants of the Boston Edison Illuminating Company, etc.

The subject of the design, operation, and maintenance of central stations forms an extended and attractive branch of electrical engineering. The design of a successful station requires scientific training, extensive experience, and technical ability. Knowledge of electrical subjects alone will not suffice, as civil and mechanical engineering ability is called into play as well, while ultimate success depends largely on financial conditions. Thus, with unlimited capital, a station of high economy of operation may be designed and constructed, but the business may be such that the fixed charges for money invested will more than equal the difference between the receipts of the company and the cost of the generation of power alone. In such cases it is better to build a cheaper station and one not possessing such extremely high economy, but on which the fixed charges are so greatly reduced that it may be operated at a profit to the owners.

The designing engineer should be thoroughly familiar with the nature and extent of the demand for power and with the probable increase in this demand. Few systems can be completed for their ultimate capacity at first and, at the same time, operated economically. Only such generating units, with suitable reserve capacity, as are necessary to supply the demand should be installed at first, but all apparatus should be arranged in such a manner that future extensions can be readily made.

The subject of power stations, as here treated, will consider the following general topics:

Location of station and substation, with choice of system to be employed.
Steam plants, boilers, piping, prime movers, etc.
Hydraulic plants.
The use of other prime movers.
The electrical plant, generators, and exciters, switching apparatus, etc.
Buildings.
Station records, methods of charging for power, etc.

LOCATION OF THE GENERATING STATION.

The choice of a site for the generating station is very closely connected with the selection of the system to be used, which system, in turn, depends largely on the nature of the demand, so that it is a little difficult to treat these topics separately. Several possible sites are often available, and we may either consider the requirements of an ideal location, selecting the available one which is nearest to this in its characteristics, or we may select the best system for a given area and assume that the station may be located where it would be best adapted to this system. Wherever the site may be, it is possible to select an efficient system, though not always an ideal one.

The following points should be considered in the location of a station, no matter what the system used:

1. Accessibility.
2. Water supply.
3. Stability of foundation.
4. Surroundings.
5. Facility for extension.
6. Cost of real estate.

The station should be readily accessible on account of the delivery of fuel and stores, and of the machinery, while it should be so located that ashes and cinders may be easily removed. If possible, the station should be located so as to be reached by both rail and water, though the former is generally more desirable. If the coal can be delivered to the bunkers directly from the cars, the very important item of the cost of handling fuel may be greatly reduced. Again, the station should be in such a location that it may be readily reached by the workmen.

Cheap and abundant water supply for both boilers and condensers is of utmost importance in locating a steam station. The quality of the water supply for the boiler is of more importance than the quantity. It should be as free as possible from impurities which are liable to corrode the boilers, and for this reason water from the town mains is often used, even when other water is available, as it is possible to economize in the use of water by the selection of proper condensers. The supply for condensing purposes should be abundant, otherwise it is necessary to install extensive cooling apparatus which is costly and occupies much space.

The machinery, as well as the buildings, must have stable foundations, and it is well to investigate the availability of such foundations when selecting the site.

In the operation of a power plant using coal or other fuels, certain nuisances arise, such as smoke, noise, or vibration, etc. For this reason it is preferable to locate where there is little liability to complaint on account of these causes, as some of these nuisances are costly and difficult or even impossible to prevent.

A station should be located where there are ample facilities for extension and, while it may not always be advisable to purchase land sufficient for these extensions at first, if there is the slightest doubt in regard to being able to purchase it later, it should be bought at once, as the station should be as free as possible from risk of interruption of its plans. Often real estate is too high for purchasing a site in the best location, and then the next best point must be selected. A consideration of all the factors involved is necessary in determining whether or not this cost is too high. In densely populated districts it is necessary to economize greatly with the space available, but it is generally desirable that the machinery may all be placed on the ground floor and that adequate provision may be made for the storage of fuel, etc.

The location of substations is usually fixed by other conditions than those which determine the site of the main power house. Since, in the simple rotary converter substation, neither fuel or water are necessary and there is little noi , it
may be located wherever the cost of real
vided suitable foundation may be co

between substations depends entirely on the selection of the system and the nature of the service.

Where low voltages are used it is essential that the station be located as near the center of the system as possible. This center is located as follows:

Having determined the probable loads and their points of application for the proposed system, these loads are indicated on a drawing with the location of the same shown to scale. The center of gravity of this system, considering each load as a weight, is then found and its location is the ideal location, as regards amount of copper necessary for the distributing system.

Consider Fig. 1, which shows the location of five different loads, which in this case are indicated by number of amperes. Combining loads A and B, we have $Ax = By$. $x + y = a$. Solving these equations we find that A and B may be considered as a load of A + B amperes at F. Similarly, C and D, E and F, and G and H may be combined giving us I, the center of the system. The amount of copper necessary for a given regulation runs up very rapidly as the distance of the station from this point increases.

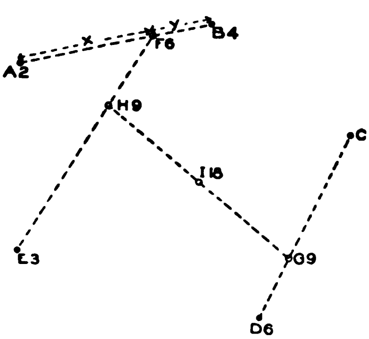


Fig. 1.

Selection of System. General rules only can be stated for the selection of a system to be used in any given territory for a certain class of service.

For an area not over two miles square and a site reasonably near the center, for lighting and ordinary power purposes, direct-current, low-pressure, three-wire systems may be used. Either 220 or 440 volts may be used as a maximum voltage, and motors should, preferably, be connected across the outside wires of the circuits. Five-wire systems with 440 volts maximum potential have been used, but they require very careful balancing of the load if the service is to be satisfactory. 220-volt lamps are giving good satisfaction; moderate-size, direct-current motors may be readily built for this pressure and constant-potential arc lamps may be operated on this voltage though not so economically as on 110 volts, if single lamps are used. For direct-current railway work, the limit of the distance to which power may be economically delivered with an initial pressure of 600 volts is from five to seven miles, depending on the traffic.

If the area to be served is materially larger than the above, or distances for direct-current railways greater, either of two different schemes may be adopted. Several stations may be located in the territory and operated separately or in multiple on the various loads, or one large power house may be erected and the energy transmitted from this station at a high voltage to various transformers or transformer substations which, in turn, transform the voltage to one suitable for the receivers. Local conditions usually determine which of these two shall be used.

The use of several low-tension stations operating in multiple is recommended only under certain conditions, namely, that the demand is very heavy and fairly uniformly distributed throughout the area, and suitable sites for the power house can be readily obtained. Such conditions rarely exist and it is a question whether or not the single station would not be just as suitable for such cases as where the load is not so congested.

One reason why a large central station is preferred to several smaller stations is that large stations can be operated more economically, owing to the fact that large units may be used and they can be run more nearly at full load. There is a gain in the cost of attendance, and labor-saving devices can be more profitably installed. The location of the power plant is not determined to such a large extent by the position of the load, but other conditions, such as water supply, cheap real estate, etc., will be the governing factors. In several cities, notably New York and Boston, large central stations are being installed to take the place of several separate stations, the old stations being changed from generating power houses to rotary-converter substations. Both direct-current low-tension machines, to supply the neighboring districts, and high-tension alternating-current, for supplying the outlying or residence districts, are often installed in the one st

As examples of the central station being locate
tance from the center of the load, we have

hydraulic power developments. Here it is the cheapness of the water power which determines the power house location. The greatest distance over which power is transmitted electrically at present is in the neighborhood of 200 miles.

If a high-tension alternating-current system is to be installed, there remains the choice of a polyphase or single-phase machine as well as the selection of voltage for transmission purposes. As pointed out in "Power Transmission", polyphase generators are cheaper than single-phase generators and, if necessary, they can be loaded to about 80% of their normal capacity, single-phase, while motors can be more readily operated from polyphase circuits. If synchronous motors or rotary converters are to be installed, a polyphase system is necessary. The voltage will be determined by the distance of transmission, care being taken to select a value considered as standard, if possible. Generators are wound giving a voltage at the terminals as high as 15,000 volts, but in many districts it is desirable to use step-up transformers for voltages above 6,600 on account of liability to troubles from lightning.

With the development of the single-phase railway motor, central stations generating single-phase current only, will be built in larger sizes than previously, as their use heretofore has been limited to lighting stations.

Size of Plant. A few general notes in regard to the design of plants will be given here, the several points being taken up more in detail later.

Direct driving of apparatus is always superior to methods of gearing or belting as it is efficient, safe, and reliable, but it is not as flexible as shafting and belts. and on this account its adoption is not universal.

Speeds to be used will depend on the type and size of the generating unit. Small machines are always cheaper when run at high speeds, but the saving is less on large generators. For large engines, slow speed is always preferable.

It is desirable that there be a demand for both power and lighting, and a station should be constructed which will serve both purposes. The use of power will create a day load for a lighting station which does much to increase its ultimate efficiency and, as a rule, its earning capacity.

In addition to generator capacity necessary to supply the load, a certain amount of reserve, either in the way of additional units or overload capacity, must be installed. The probable load for say three years can be closely estimated and this, together with the proper reserve, will determine the size of the station. The plant as a whole, including all future extensions, should be planned at the start as extensions will then be greatly facilitated. Usually it will not be desirable to begin extensions for at least three years after the first part of the plant has been erected.

Enough units must be installed so that one or more may be laid off for repairs, and there are several arguments in favor of making this reserve in the way of overload capacity, for the generators at least. Some of these arguments are: Reserve is often required at short notice, notably in railway plants. With overload capacity, rapid increase of load, such as occurs in lighting stations when darkness comes on suddenly, may be more readily taken care of. There is always a factor of safety in machines not running to their fullest capacity. Reserve capacity is cheaper in this form than if installed as separate machines. As a disadvantage, we have a lower efficiency, due to machines not usually running at full load, but in the case of generators this is very slight.

With an overload capacity of $33\frac{1}{3}\%$, four machines should be the initial installment since one can be laid off for repairs if necessary, the total load being readily carried by three machines. In planning extensions, the fact that at least one machine may require to be laid off at any time should not be lost sight of, while the units should be made as large as is conducive to the best operation.

TABLE 1.

Permissible Overload 33 per cent.

	Machines added one at a time.		Machines added two at a time.		Machines added three at a time.	
	No.	Size.	No.	Size.	No.	Size.
Initial installment...........	4	500	4	500	4	500
First extension..............	1	666	2	1000	3	2000
Second "	1	888	2	2000	5	5000
Third "	1	1183	2	4000	4	5000
Fourth "	1	1577	4	4000		
Fifth "	1	2103	8	4000		
Sixth "	1	2804				

Table 1 is worked out showing the initial installment for a 2,000-K.W. plant with future extensions. It is seen from this table that adding two machines at a time gives more uniformity in the size of units—a very desirable feature.

The boilers should be of large units for stations of large capacity, while for small stations they must be selected so that at least one may be laid off for repairs.

STEAM PLANT.

BOILERS.

The majority of power stations have their machinery driven by either steam or water power, though there are many using gas engines as prime movers. If a steam plant is being considered, one of the first subjects to be taken up is the generation of the steam. The subject of boilers is one of vital importance to the successful operation of steam-driven central stations. The object of the boiler with its furnace is to abstract as much heat as possible from the fuel and impart it to the water. The various kinds of boilers used for accomplishing this more or less successfully are described in books on boilers, and we will consider here the merits of a few of the types only as regards central-station operation.

The requirements are: *First*, that steam be available throughout the twenty-four hours; the amount required at different parts of the day varying considerably. Thus, in a lighting station, the demand from midnight to 6 a. m. is very light, but toward evening, when the load on the station increases very rapidly, there is an abrupt increase in the rate at which steam must be given off. The maximum demand can be readily anticipated under normal weather conditions, but occasionally this maximum will be equaled or even exceeded at unexpected moments. For this reason a certain number of boilers must be kept under steam constantly, more or less of them running with banked fires during light loads. If the boilers have a small amount of radiating surface, the loss during idle hours will be decreased.

Second, the boilers must be economical over a large range of rates of firing and must be capable of being forced without detriment. Boilers should be provided which work economically for the hours just preceding and following the maximum load while they may be forced, though running at lower efficiency, during the peak.

Third, coming to the commercial side of the question, we have first cost, cost of maintenance, and space occupied. The first cost, as does the cost of maintenance, varies with the type and pressure of the boiler. The space occupied enters as a factor only when the situation of the station is such that space is limited, or when the amount of steam piping becomes excessive. In some city plants, space may be the determining feature in the selection of boilers.

The **Cornish and Lancashire** boilers differ only in the number of cylindrical tubes in which furnaces are placed. As many as three tubes are placed in the largest sizes (seldom used) of the Lancashire boilers. They are made up to 200 pounds steam pressure and possess the following features:

1. High efficiency at moderate rates of combustion.
2. Low rate of depreciation.
3. Large water space.
4. Easily cleaned.
5. Large floor space required.
6. Cannot be readily forced.

The Galloway boiler differs from the Lancashire boiler in that there are cross tubes in the flues.

In the **Multitubular boiler** the number of tubes is greatly increased and their size diminished. Their heating surface is large and they steam rapidly. They are used extensively for power-station work.

The chief characteristics of the **water-tube boilers,** of which there are many types, are:

1. Moderate floor space.
2. Ability to steam rapidly.
3. Good water circulation.
4. Adapted to high pressure.
5. Easily transported and erected.
6. Easily repaired.
7. Not easily cleaned.
8. Rate of deterioration greater than for Lancashire boiler.
9. Small water space, hence variation in pressure with varying demands for steam.
10. Expensive setting.

Marine boilers require no setting. Among their advantages and disadvantages may be mentioned:

1. Exceedingly small space necessary.
2. Radiating surface reduced.
3. Good economy.
4. Heavy and difficult to repair.
5. Unsuitable for bad water.
6. Poor circulation of water.

Another type of boiler, known as the Economic, is a combination of the Lancashire and multitubular boilers, as is the marine boiler. It is set in brickwork and arranged so that the gases pass under the bottom and along the sides of the boiler as well as through the tubes. It may be compared with other boilers from the following points:

1. Small floor space.
2. Less radiating surface than the Lancashire boiler.
3. Not easily cleaned.
4. Repairs rather expensive.
5. Requires considerable draft.

As regards first cost, boilers installed for 150 pounds pressure and the same rate of evaporation, will run in the following order: Galloway and Marine, highest first cost, Economic, Lancashire, Babcock & Wilcox. The increase of cost, with increase of steam pressure, is greatest for the Economic and least for the water-tube type.

Deterioration is less with the Lancashire boiler than with the other types.

The floor space occupied by these various types built for 150 pounds pressure and 7,500 pounds of water, evaporated per hour, is given in Table 2.

TABLE 2.

Kind of Boiler.	Floor Space in Sq. Ft.
Lancashire	408
Galloway	371
Babcock and Wilcox	200
Marine wet-back	120
Economic	210

The percentage of the heat of the fuel utilized by the boiler is of great importance, but it is difficult to get reliable data in regard to this. Table 3 is taken from Donkin's "Heat Efficiency of Steam Boilers", and will give some idea of the efficiencies of the different types. Economizers were not used in any of these tests, but they should always be used with the Lancashire type of boiler.

TABLE 3.

Kind of Boiler.	No. of Experiments.	Mean Efficiency of two best Experiments.	Lowest Efficiency.	Mean Efficiency of all Experiments.
Lancashire hand-fired	107	79.5	42.1	62.3
Lancashire machine-fired	40	73.0	51.9	64.2
Cornish hand-fired	25	81.7	53.0	68.0
Babcock and Wilcox hand-fired	49	77.5	50.0	64.9
Marine wet-back hand-fired	6	69.6	62.0	66.0
Marine dry-back hand-fired	24	75.7	64.7	69.2

It is well to select a boiler from 20 to 50 pounds in excess of the pressure to be used, as its life may thus be considerably extended, while, when the boiler is new, the safety valve need not be set so near the normal pressure, and there is less steam wasted by the blowing off of this valve. Again, a few extra pounds of steam may be carried just previous to the time the peak of the load is expected. For pressures exceeding 200 or, possibly, 150 pounds, a water-tube boiler should be selected.

In large stations, it is preferable to make the boiler units of large capacity, to do away as much as possible with the extra piping and fittings necessary for each unit. Water-tube boilers are best adapted for large sizes. These may be constructed for 150 pounds pressure, large enough to evaporate 20,000 pounds of water per hour, at an economical rate.

To sum up — For stations of moderate size and with medium pressures with plenty of space, use Lancashire or fire-tube boilers; for high pressure or large units, select water-tube boilers; where space is limited, install marine boilers, although they are not as safe as water-tube boilers for high pressures.

Steam Piping. The piping from the boilers to the engines should be given very careful consideration. Steam should be available at all times and for all engines. Freedom from serious interruptions due to leaks or breaks in the piping is brought about by very careful design and the use of good material in construction. Duplicate piping is used in many instances. Provision must always be made for variations in length of the pipe with variation of temperature. For plants using steam at 150 pounds pressure, the variation in the length of steam pipe may be as high as 2.5

inches for 100 feet, and at least 2 inches for 100 feet should always be counted upon.

Arrangement. Fig. 2 shows a simple diagram of the "ring" system of piping. The steam passes from the boiler by two paths to the engine and any section of the piping may be cut out by the closing of two valves. Simple ring systems have the following characteristics:

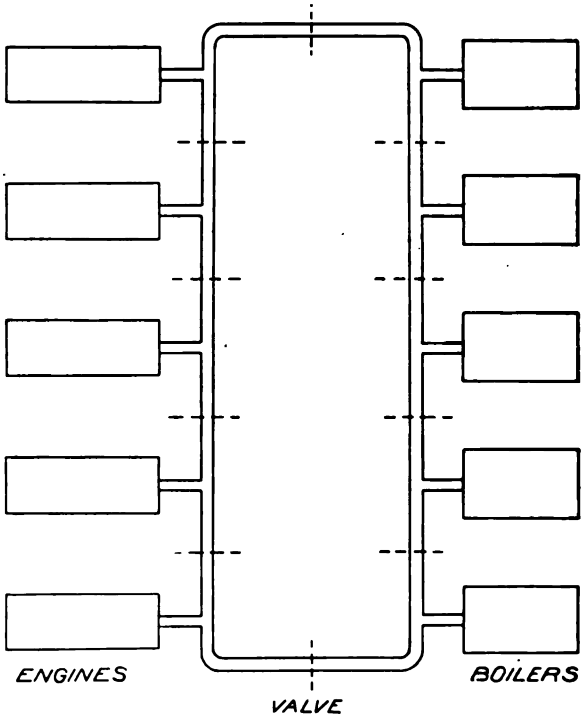
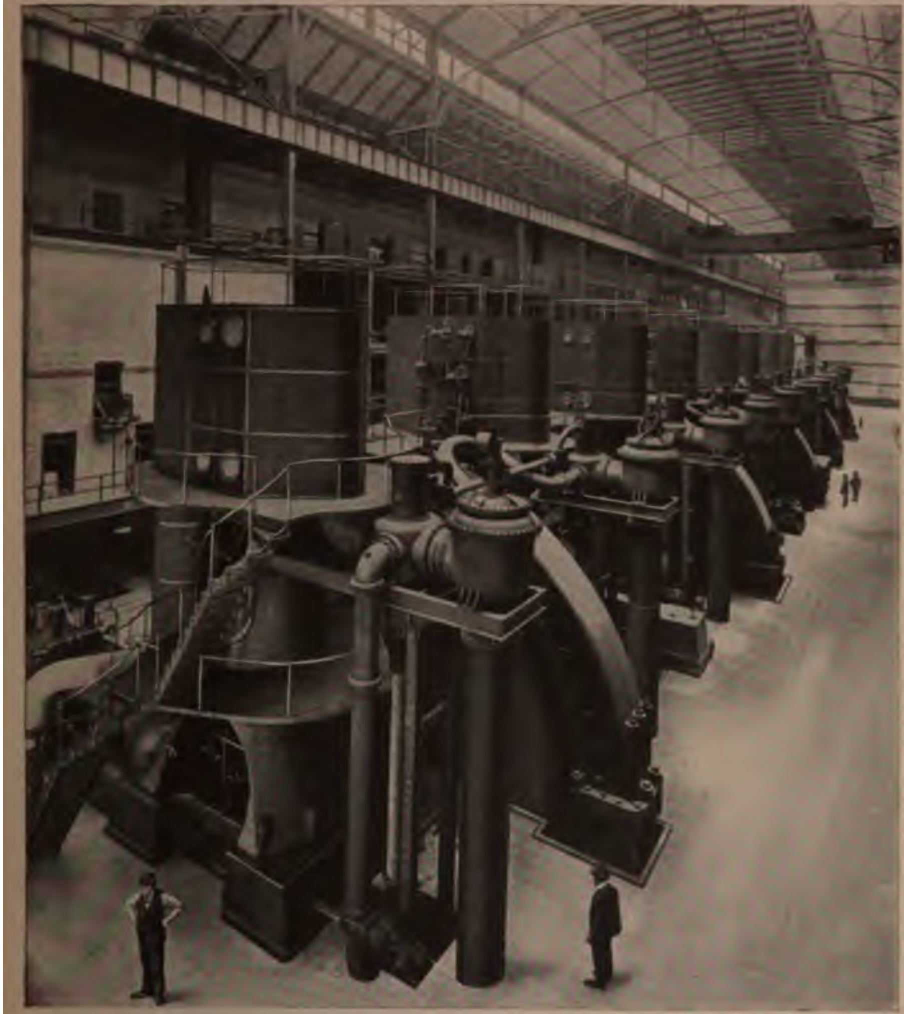


Fig. 2.

1. The range, as the main pipe is called, must be of uniform size and large enough to carry all of the steam when generated at its maximum rate.
2. A damaged section may disable one boiler or one engine.
3. Several large valves are required.
4. Provision may be readily made to allow for expansion of pipes.

Cross connecting the ring system, as shown in Fig. 3, changes these characteristics as follows:

1. Size of pipes and consequent radiating surface is reduced.
2. More valves needed but they are of smaller size.
3. Less easy to arrange for expansion of the pipes.



POWER HOUSE OF NEW YORK SUBWAY.

Showing Five of the Nine 12,000 Horse-Power Allis-Chalmers Engines.

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ASTOR, LENOX
TILDEN FOUNDATIONS

If the system is to be duplicated, that is, two complete sets of main pipes and feeders installed (see Fig. 4), two schemes are in use:

1. Each system is designed to operate the whole station at maximum load with normal velocity and loss of pressure in the pipes, and only one system is in use at a time. This has the disadvantage that the idle section is liable not to be in good operating condition when needed. Large pipes must be used for each set of mains.

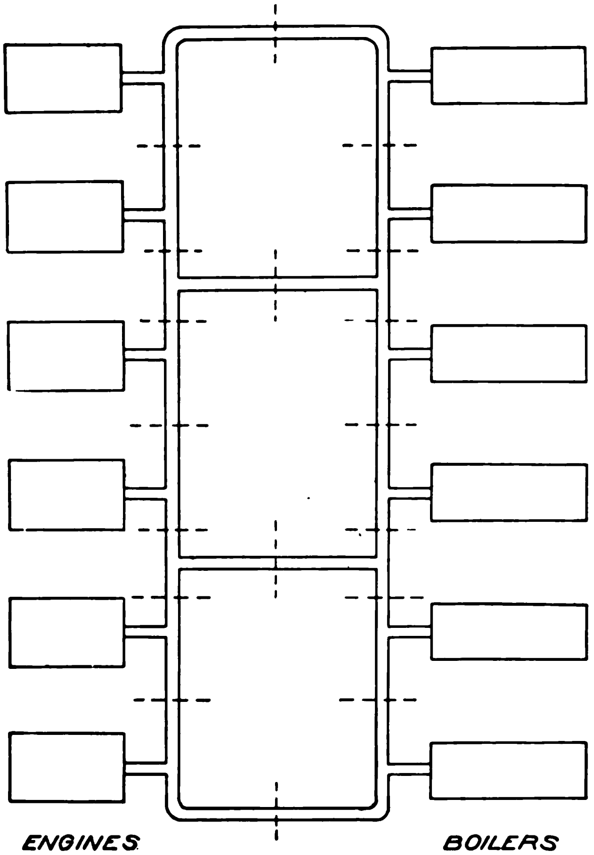

Fig. 3.

2. The two systems may be made large enough to supply steam at normal loss of pressure when both are used at the same time, while either is made large enough to keep the station running should the other section need repairs. This has the advantages of less expense, and both sections of pipe are normally in use; but it has the disadvantages of more radiating surface to the pipes and consequent condensation for the sa [illegible] city for furnishing steam.

Complete interchangeability of units cannot be arranged for if the separate engine units exceed 400 to 500 horse power. Since engine units can be made larger than boiler units, it becomes necessary to treat several boiler units as a single unit, or battery, these batteries being connected as the single boilers already shown. For still larger plants the steam piping, if arranged to supply any engines from any batteries of boilers, would be of enormous size. If the boilers do not occupy a greater length of floor space than the engines, Fig. 5 shows a good arrangement of units. Any engine can be fed from either of two batteries of boilers and the liability of serious interruptions of service due to steam pipes or boiler trouble is very remote.

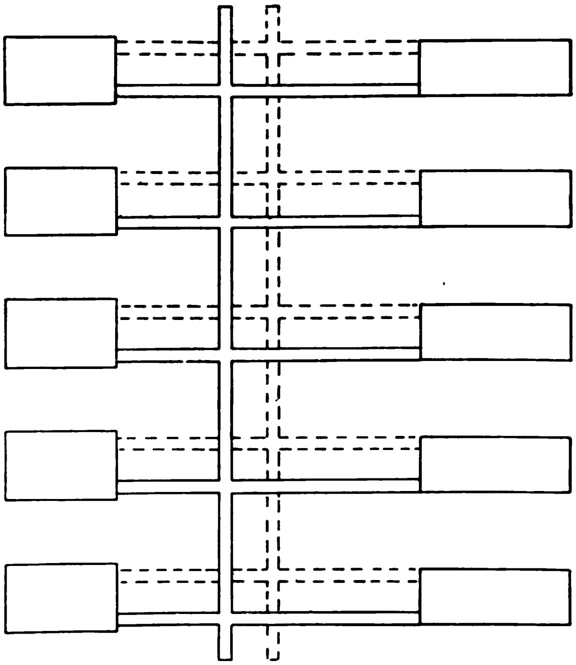

Fig. 4.

Material. Steel pipe, lap welded and fastened together by means of flanges, is to be recommended for all steam piping. The flanges may be screwed on the ends of sections and calked so as to render this connection steam tight, though in large sizes it is better to have the flanges welded to the pipes. This latter construction costs no more for large pipes and is much more reliable. All valves and fittings are made in two grades or weights, one for low pressures, and the other for high pressures. The high-pressure fittings should always be used for electrical stations. Gate valves should always be selected and, in large sizes, they should be provided with a by-pass.

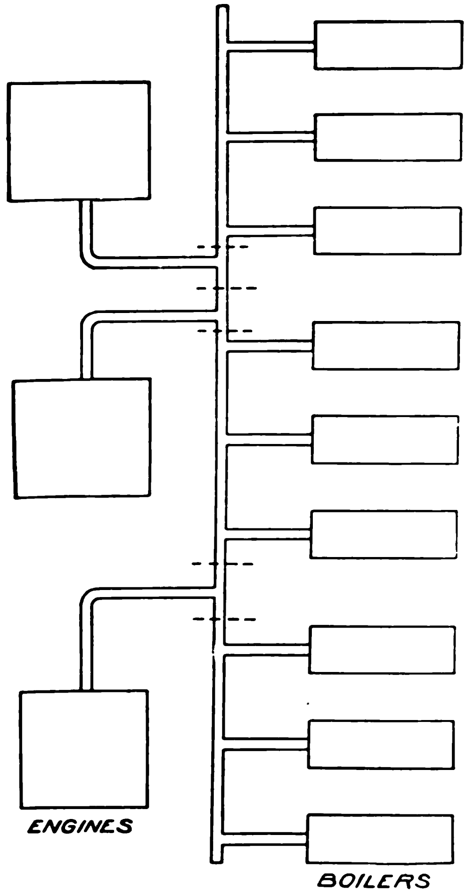

Fig. 5.

Asbestos, either alone or with copper rings, vulcanized india rubber, asbestos and india rubber, etc., are used for packing between flanges to render them steam tight. Where there is much expansion, the material selected should be one that possesses considerable elasticity. Joints for high-pressure systems require much more care than those where steam is used at a low pressure, and the number of joints should be reduced to a minimum by using long sections of pipe.

A list of the various fittings required for steam piping, together with their descriptions, is given in books on boilers. One precaution to be taken is to see that such fittings do not become too numerous or complicated, and it is well not to depend too much on automatic fittings. Steam separat be large enough to serve as a reservoir of steam for tl alize, to a certain extent, the velocity of flo

In providing for the expansion of pipes due to change of temperature, "U" bends made of steel pipe and having a radius of curvature not less than six times, and preferably ten times the diameter of the pipe, are preferred. Copper pipes cannot be recommended for high pressures, while slip expansion joints are most undesirable on account of their liability to bind.

The size of steam pipes is determined by the velocity of flow. Probably an average velocity of 60 feet per second would be better than 100 feet per second, though in some cases where space is limited a velocity as high as 150 feet per second has been used.

The loss in pressure in steam pipes may be obtained from the following formula:

$$p_1 - p_2 = \frac{Q^2 w L}{c^2 d^5}$$

where $p_1 - p_2$ = loss in pressure in pounds per sq. in.
Q = quantity of steam in cu. ft. per minute.
d = diameter of pipe in inches.
L = length in feet.
w = weight per cu. ft. of steam at pressure p_1.
c = constant depending on size of pipe.

Values of c are as follows:

Diameter of pipe..	½"	1"	2"	3"	4"	5"	6"	7"	8"	9"	10"
Value of c.........	36.8	45.3	52.7	56.1	57.8	58.4	59.5	60.1	60.7	61.2	61.8

Diameter of pipe...............	12"	14"	16"	18"	20"	22"	24"
Value of c......................	62.1	62.3	62.6	62.7	62.9	63.2	63.2

In mounting the steam pipe, it should be fastened rigidly at one point, preferably near the center of a long section, and allowed a slight motion longitudinally at all other supports. Such supports may be provided with rollers to allow for this motion, or the pipe may be suspended from wrought-iron rods which will give a flexible support. Practice differs in the location of the steam piping, some engineers recommending that it be placed underneath the engine room floor and others that it be located high above the engine room floor. In any case it should be made easily accessible, and the valves should be located so that nothing will interfere with their operation. Proper provision must be made for draining the pipes.

All piping as well as joints should be carefully covered with a good quality of lagging as the amount of steam condensed in a bare pipe, especially if of any great length, is considerable. In selecting a lagging the following points should be noticed. Covering for steam pipes should be incombustible, should present a smooth surface, should not be easily damaged by vibration or steam, and should have as large a resistance to the passage of heat as possible. It must not be too thick, otherwise the increased radiating surface will counterbalance the resistance to the passage of heat.

The loss of power in steam pipes due to radiation is given as follows:

$H = .262rLd.$
H = loss of power in heat units.
d = diameter of pipe.
L = length of pipe in feet.
r = constant depending on steam pressure and pipe covering.

Steam pressure in pounds (absolute)	40	65	90	115
Values of r for uncovered pipe	437	555	620	684
Value of r for pipe covered with 2 inches of hair felt	48	58	66	73

Referring to table in books on boilers, the relative values of different materials used for covering steam pipes may be found.

Superheated Steam reduces condensation in the engines as well as in the piping, and increases the efficiency of the system. Its use was abandoned for several years, due to difficulties in lubricating and packing the engine cylinders, but by the use of mineral oils and metallic packing, these difficulties have been done away with to a large extent, while steam turbines are especially adapted to the use of superheated steam. The application of heat directly to steam, as is done in the superheater, increases the efficiency of the boilers. Table 4 shows the increase in boiler efficiency for a certain boiler test, the results being given in pounds of water changed to dry, saturated steam. Tests on various engines show a gain in efficiency as high as 9% with a superheat of 80° to 100° F, while special tests in some cases show even a greater gain.

TABLE 4.

Amount of superheat.	Water evaporated per lb. of coal.	
	Without superheat.	With superheat.
40 degrees F.	7.82	9.99
42 "	6.42	7.06
55 "	6.00	7.00
56.5 "	6.78	8.66
55.2 "	7.15	8.65

Superheaters are very simple, consisting of tubular boilers containing steam instead of water, and either located so as to utilize the heat of the gases, the same as economizers, or separately fired. They should be arranged so that they may be readily cut out of service, if necessary, and provision must be made for either flooding them or turning the hot gases into a by-pass, as the tubes would be injured by the heat if they contained neither water nor steam.

FEED WATER AND FEEDING APPLIANCES.

All water, such as can be obtained for the feeding of boilers, contains some impurities, among the most important of which as regards boilers are soluble salts of calcium and magnesium. Bicarbonates of the alkaline earths cause precipitations on the interior of boilers, forming "scale". Sulphate of lime is also deposited by concentration under pressure. Scale, when formed, not only decreases the efficiency of the boiler but also causes deterioration, for if sufficiently thick, the diminished conducting power of the boiler allows the tubes or plates to be overheated and to crack or burst. Again, the scale may keep the water from contact with sections of the heated plates for some time and then, giving way, large volumes of steam are generated very quickly and an explosion may result.

Some processes to prevent the formation of scale are used, which affect the water after it enters the boilers, but they are not to be recommended, and any treatment the water receives should affect it previous to its being fed to the boilers. Carbonates and a small quantity of sulphate of lime may be removed by heating in a separate vessel. Large quantities of sulphate of lime must be precipitated chemically.

Sediment, small particles of matter in suspension, must be removed by allowing the water to settle. Vegetable matters are sometimes present, which cause a film to be deposited. Certain gases, in solution—such as oxygen, nitrogen, etc.—cause pitting of the boiler. This effect is neutralized by the addition of chemicals. Oil, from the engine cylinder, is particularly destructive to boilers and when present in the condensed steam must be carefully removed.

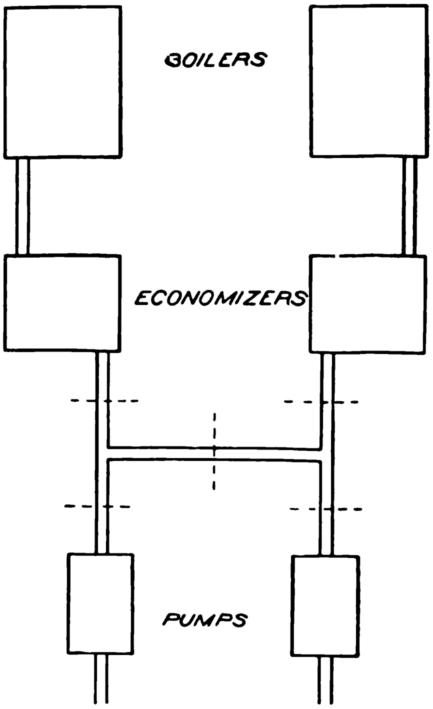

Fig. 6.

Both feed pumps and injectors are used for feeding the water to the boilers. Feed pumps may be either steam or motor-driven. Steam-driven pumps are very inefficient, but they are simple and the speed is easily controlled. Motor-driven pumps are more efficient and neater, but more expensive and more difficult to regulate efficiently over a wide range of speed. Direct-acting pumps may have feed-water heaters attached to them, thus increasing the efficiency of the apparatus as a whole. The supply of electrical energy must be constant if motor-driven pumps are to be used.

Feed pipes must be arranged so as to reduce the risk of failure to a minimum, and for this reason they are almost always duplicated. More than one water supply is also recommended if there is the slightest danger of interruption on this account mmon arrangement of feed-water apparatus is to inst pumps supplying either of two mains from w'

TABLE 5.

Giving Rate of Flow of Water, in Feet per Minute, through Pipes of Various Sizes, for Varying Quantities of Flow.

Gallons per Min.	¾ in.	1 in.	1¼ in	1½ in.	2 in.	2½ in.	3 in.	4 in.
5	218	122½	78½	54½	30½	19½	13½	7⅔
10	436	245	157	109	61	38	27	15⅓
15	653	367½	235½	163½	91½	58½	40½	23
20	872	490	314	218	122	78	54	30⅔
25	1090	612½	392½	272½	152½	97½	67½	38⅓
30		735	451	327	183	117	81	46
35		857½	549½	381½	213½	136½	94½	53⅔
40		980	628	436	244	156	108	61⅓
45		1102½	706½	490½	274½	175½	121½	69
50			785	545	305	195	135	76⅔
75			1177½	817½	457½	292½	202½	115
100				1090	610	380	270	153⅓
125					762½	487½	337½	191⅔
160					915	585	405	230
175					1067½	682½	472½	268⅓
200					1220	780	540	306⅔

nections are taken. This is a complicated and costly system of piping. Fig. 6 shows a scheme used for feeding two boilers in which each pump is capable of supplying both boilers. Pipes should be ample in cross-section, and, in long lengths, allowance must be made for expansion. Cast iron or cast steel is the material used for their construction, while the joints are made by means of flanges fitted with rubber gaskets.

Table 5 gives the rate of flow of water in feet per minute through pipes of various sizes. A flow of 10 gallons per minute for each 100 H. P. of boiler equipment should be allowed without causing an excessive velocity of flow in the pipes.

BOILER FOUNDATIONS, FURNACES AND DRAFT.

The economical use of coal depends, to a large extent, on the setting of the boiler and proper dimensions of the furnaces. Internally-fired boilers require support only, while the setting of externally-fired boilers requires provision for the furnaces. Common brick, together with fire brick for the lining of portions exposed to the hot gases, are used almost invariably for boiler settings. It is customary to set the boiler units up in batteries of two, using a 20-inch wall at the sides and a 12-inch wall between the two boilers. The instructions for settings furnished by the manufacturers should be carefully followed out as they are based on conditions which give the best results in the operation of their boilers.

Natural Draft is the most commonly used and is the most satisfactory under ordinary circumstances. In determining the size of the chimney necessary to furnish this draft, the following formula is given by Kent:

$$A = \frac{.06\ F}{\sqrt{h}} \text{ or } h = \left(\frac{.06\ F}{A}\right)^2$$

A = area of chimney in sq. ft.
h = height of chimney in ft.
F = pounds of coal per hour.

The height of chimney should be assumed and the area calculated, remembering that it is better to have the chimney too large than too small.

The chimney may be of either brick or iron, the latter having a less first cost but requiring repairs at frequent intervals. General rules for the design of a chimney may be given as follows: The external diameter of the base should not be less than $\frac{1}{10}$ of the height. Foundations must be of the best. Interiors should be of uniform section and lined with fire brick. There must be an air space between the lining and chimney proper. The exterior should have a taper of from $\frac{1}{16}$ to $\frac{1}{4}$ inch to the foot. Flues should be arranged symmetrically.

Fig. 7 shows the construction of a brick chimney of good design, this chimney being used with boilers furnishing engines which develop 14,000 H. P.

Mechanical Draft is a term which may be used to embrace both forced and induced draft. The different systems of mechanical draft are described in books on boilers. The first cost of mechanical-draft systems is less than that of a chimney, but the operation and repair are much more expensive and there is always the risk of break-down. Artificial draft has the advantage that it can be varied within large limits and it can be increased to any desired extent, thus allowing the use of low grades of coal.

Firing of Boilers and Handling of Fuel. Coal is used for fuel to a greater extent than any other material, though oil, gas, wood, etc., are used in some localities. Local conditions, such as availability, cost, etc., should determine the material to be used and no general rules can be given. Data regarding the relative heating values of different fuels show the following general figures: One pound of petroleum, about ⅐ of a gallon, is equivalent, when used with boilers, to 1.8 pounds of coal and there is less deterioration of the furnace with oil. 7½ to 12 cubic feet of natural gas are required as the equivalent of one pound of coal, depending on the quality of the gas. 2¼ pounds of dry wood is assumed as the equivalent of one pound of coal.

When coal is used, it requires stoking and this may be accomplished either by hand or by means of mechanical stokers, many forms of which are available. Mechanical stoking has the advantage over hand stoking that the fuel may be fed to the furnace more uniformly and the fires and boilers are not subjected to sudden blasts of cold air as is the case when the fire doors are opened; a poorer grade of coal may be burned, if necessary, and the trouble due to smoke is much reduced. It may be said that mechanical stokers are used almost universally in the more important elec-

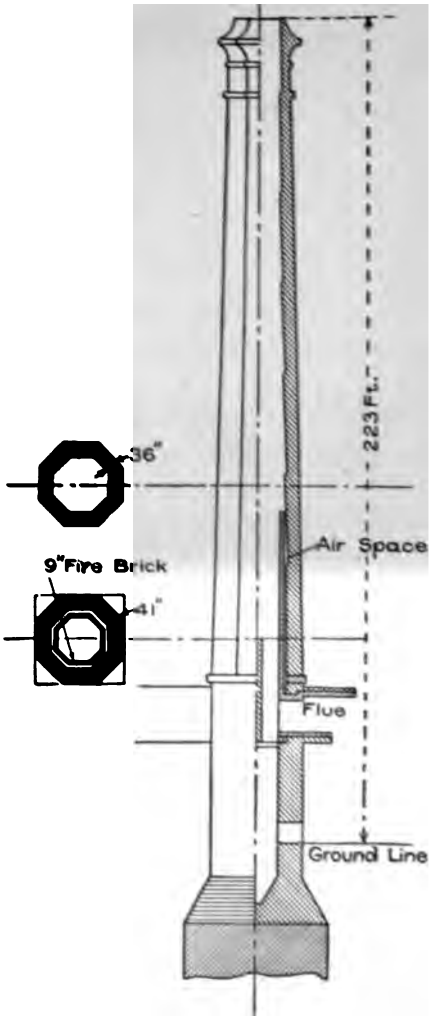

Fig. 7.

trical plants. Economic use of fuel requires great care in firing, especially if it is done by hand.

Where gas is used, the firing may be made nearly automatic, and the same is true of oil firing, though the latter requires more complicated burners, as it is necessary that the oil be vaporized.

In large stations, operated continuously, it is desirable that, as far as possible, all coal and ashes be handled by machinery, though the difference in cost of operation should be carefully considered before installing extensive coal-handling machinery. Machinery for automatically handling the coal will cost from $7.50 to $10 per horse-power rating of boilers for installation, while the ash-handling machinery will cost from $1.50 to $3.00 per horse power.

The coal-handling devices usually consist of chain-operated conveyors which hoist the coal from railway cars, barges, etc., to overhead bins from which it may be fed to the stokers. The ashes may be handled in a similar manner, by means of scraper conveyors, or small cars may be used. Either steam or electricity may be used for driving this auxiliary apparatus.

It is always desirable that there be generous provision for the storage of fuel sufficient to maintain operations of the plant over a temporary failure of supply.

STEAM ENGINES AND TURBINES.

The choice of steam prime movers is one which is governed by a number of conditions which can be treated but briefly here. The first of these conditions relates to the speed of the engine to be used. There is considerable difference of opinion in regard to this as both high and low-speed plants are in operation, which are giving good satisfaction. Slow-speed engines have a higher first cost and a higher economy. Probably in sizes up to 250 K.W. the generator should be driven by high-speed engines, above which the selection of either type will give satisfaction until sizes of say above 500 indicated horse power, when the slow-speed type is to be recommended. Drop valves cannot be used with satisfaction for speeds above about 100 revolutions per minute, hence high-speed engines must use direct-driven valve gears, usually governed by shaft governors. Corliss valves are used on nearly all slow-speed engines.

The steam pressure used should be at least 125 pounds per square inch at the throttle and a pressure as high as 150 to 160 pounds is to be preferred.

Close regulation and uniform angular velocity are required for driving generators, especially alternators which are to operate in parallel. This means sensitive and active governors, carefully designed fly-wheels and proper arrangement of cranks when more than one is used.

For large plants or plants of moderate size, compound condensing engines are almost universally installed. The advantage of these engines in increased economy are in part counterbalanced by higher first cost and increased complications, together with the pumps and added water supply necessary for the condensers. The approximate saving in amount of steam is shown in table 6, which applies to a 500 horse-power unit.

TABLE 6.

Engine.	Pounds of Steam per H. P. hour.
Simple non-condensing	30
Simple condensing	22
Compound non-condensing	24
Compound condensing	16

Triple expansion engines are seldom used for driving electrical machinery as their advantages under variable loads are doubtful. Compound engines may be tandem or cross compound and either horizontal or vertical. The use of cross-compound engines tends to produce uniform angular velocity, but the cylinder should be so proportioned that the amount of work done by each is nearly equal. A cylinder ratio of about 3½ to 1 will approximate average conditions. Either vertical or horizontal engines may be installed, each having its own peculiar advantages. Vertical engines require less floor space, while horizontal engines have a better arrangement of parts. Either type should be constructed with heavy parts and erected on solid foundations.

Recently steam turbines have come into use, and the number of stations at present under process of design or construction which will use steam turbines is very large. Several types of turbines are described in the books on engines. In addition to these, a short review of the Curtis turbine will not be out of place since this is one of the types which is coming into extended use.

The Curtis turbine is divided into sections, each section of which may contain one, two, or more, revolving sets of buckets and stationary vanes supplied with steam from a set of expansion nozzles. By this arrangement of parts the work is divided into stages, the nozzle velocity is reduced in each stage, and the energy of the steam is effectively given up to the rotating parts. This type admits of lower speeds than the other forms of turbines. Fig. 8. shows the arrangement of nozzles, buckets, and stationary blades or guiding vanes for two stages. Governing is accomplished by shutting off the steam from some of the nozzles. A complete Curtis turbine of the vertical type, direct connected to a 5,000 K.W. three-phase alternating-current generator, is shown in Fig. 9.

The advantages claimed for this turbine are:

1. High steam economy at all loads
2. High steam economy with rapidly fluctuating loads.
3. Small floor space per K.W. capacity, reducing to a minimum the cost of real estate and buildings.
4. Uniform angular velocity.
5. Simplicity in operation and low expense for attendance.
6. Freedom from vibration.
7. Steam economy not appreciably impaired by wear or lack of adjustment in long service.
8. Adaptability to high steam pressure and high superheat without practical difficulty and with consequent improvement in economy.
9. Condensed water is kept entirely free from oil and can be returned to the boilers.

Many of these advantages apply equally well to the other types of turbines now on the market. All turbines are especially adapted to operation with superheated steam.

Engines should preferably be direct-connected as already stated, but this is not always feasible, and gearing, belt, or rope drives must be resorted to. Countershafts, belt or rope driven, arranged with pulleys and belts for the different generators, and with suitable clutches, are largely used in small stations. They consume considerable power and the bearings require attention.

Careful attention must be given to the lubrication of all running parts, and extensive oil systems are necessary in large plants.

In such systems a continuous circulation of oil over the bearings and through the engine cylinders is maintained by means of oil pumps. After passing through the bearings, the machine oil goes to a properly arranged oil-filter where it is cleaned and then pumped to the bearings again. A similar process is used in cylinder lubrication, the oil being collected from the exhaust steam and only enough new oil is added to make up for the slight amount lost. The latter system is not installed as frequently as the continuous system for bearings. In the Curtis turbine, vertical type, the oil is forced in between the two plates, forming the step bearing, at such a pressure that a thin film of oil is constantly maintained between these plates. It may be arranged so that if, for any reason, this pressure fails, the steam will be cut off from the

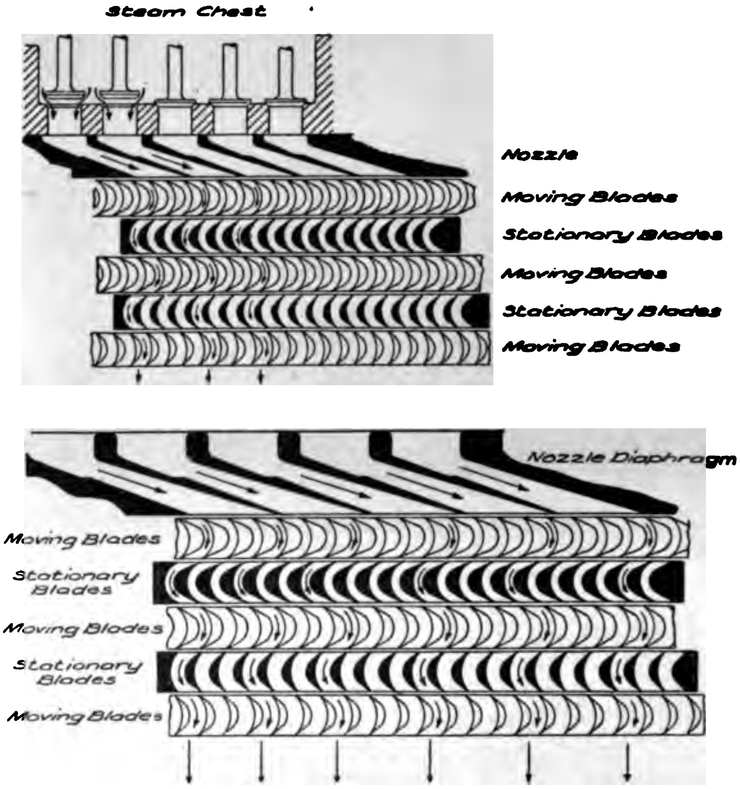

DIAGRAM OF NOZZLES AND BUCKETS IN CURTIS STEAM TURBINE.
Fig. 8.

turbine automatically. The bearings which support the shafts used with the generators at the Niagara Falls Power Companies' plants are generously flooded with oil and the turbines are arranged so as to remove a great deal of the weight of the rotating part from this bearing.

HYDRAULIC PLANTS.

Because of the relative ease with which electrical energy may be transmitted long distances, it has become quite common to locate large power stations where there is abundant water power, and to transmit the energy thus generated to localities where it is needed. This type of plant has been developed to the greatest extent in the western part of the United States, where in some cases the transmission lines are very extensive. The power houses now completed, or in the course of erection at Niagara Falls, are examples of the enormous size such stations may assume.

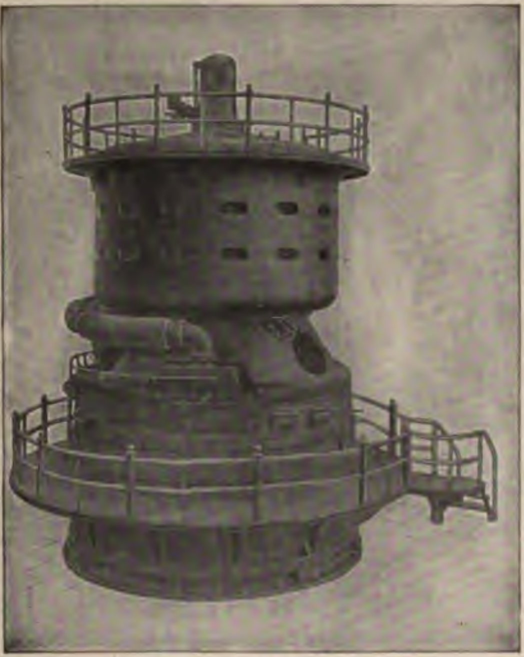

Fig. 9.

Before deciding to utilize water power for driving the machinery in central stations, the following points should be noted:

1. The amount of water power available.
2. The possible demand for power.
3. Cost of developing this power as compared with cost of plants using other sources of power.
4. Cost of operation compared with other plants and extent of transmission lines.

Hydraulic plants are often much more expensive than steam plants, but the first cost is more than made up by the saving in operating expenses.

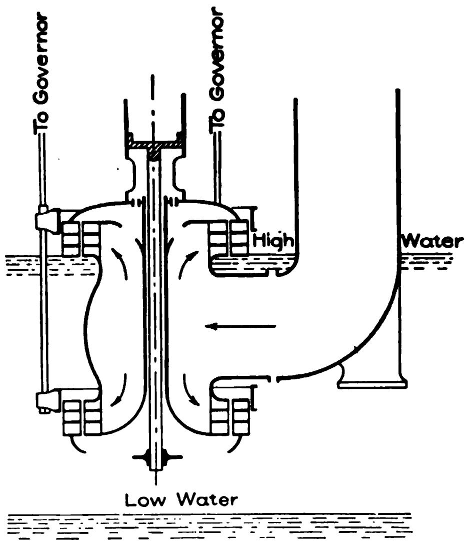

Fig. 10.

Methods for the development of water powers vary with the nature and amount of the water supply, and they may be studied best by considering plants which are in successful operation, each one of which has been a special problem in itself. A full description of such plants would be too extensive to be incorporated here, but they can be found in the various technical journals.

Water Turbines used for driving generators are of two general classes, reaction turbines and impulse turbines. The former may be subdivided into Parallel-flow, Outward-flow, and Inward-flow turbines. Parallel-flow turbines are suited for low falls, not exceeding 30 feet. Their efficiency is from 70 to 72%. Outward-flow and inward-flow turbines give an efficiency from 79 to 88%. Impulse turbines are suitable for very high falls and should be used from heads exceeding say 100 feet, though it is difficult to say at what head the reaction turbine would give place to the impulse wheel, as reaction turbines are giving good satisfaction on heads in the neighborhood of 200 feet, while impulse wheels are operated

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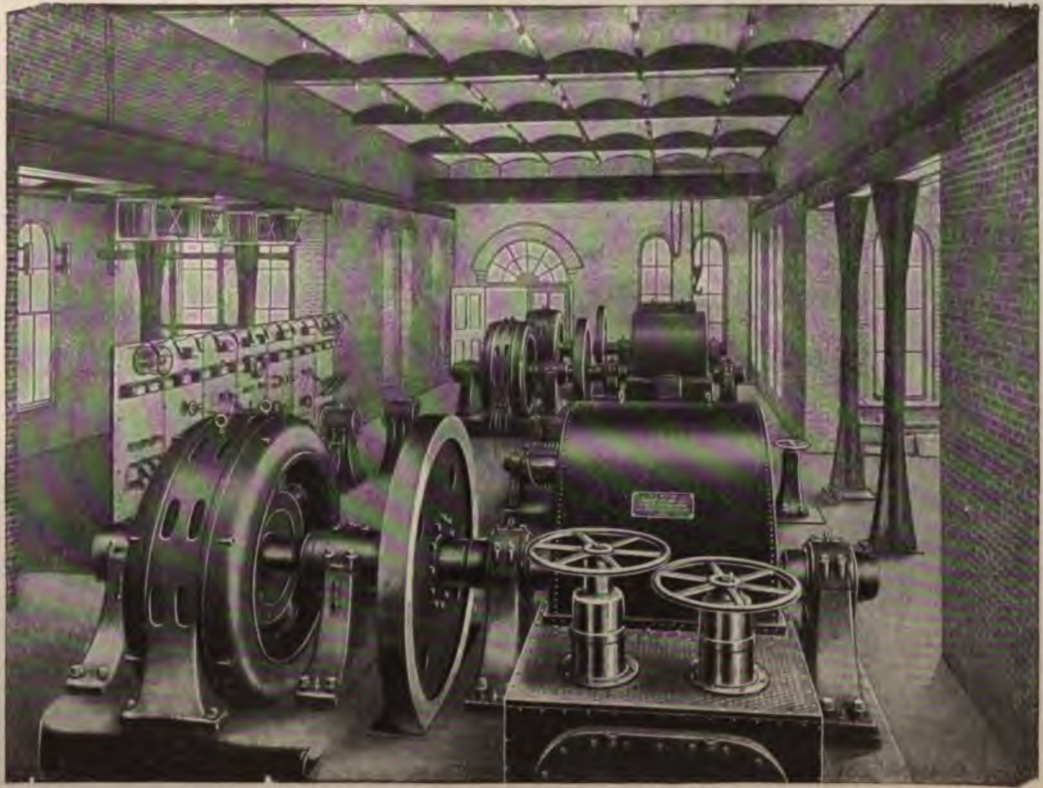


INTERIOR OF PIKES PEAK POWER STATION.

The Pelton Water Wheel Company.

with falls of but 80 feet. The Pelton wheel is one of the best known types of impulse wheels. An efficiency as high as 86% is claimed for this type of wheel under favorable conditions. Fig. 10 shows a reaction wheel and Fig. 11 illustrates a Pelton wheel.

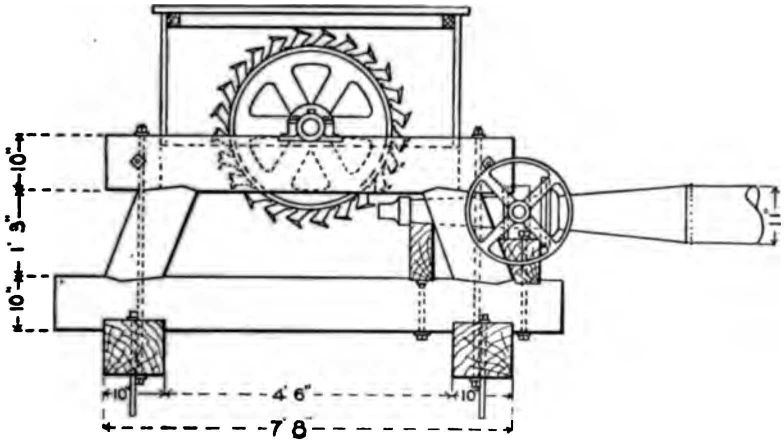


Fig. 11.

TABLE 7.

Pressure of Water.

Feet Head.	Pressure Pounds per Square Inch.	Feet Head.	Pressure Pounds per Square Inch.	Feet Head.	Pressure Pounds per Square Inch.	Feet Head.	Pressure Pounds per Square Inch.
10	4.33	105	45.48	200	86.63	295	127.78
15	6.49	110	47.64	205	88.80	300	129.95
20	8.66	115	49.81	210	90.96	310	134.28
25	10.82	120	51.98	215	93.13	320	138.62
30	12.99	125	54.15	220	95.30	330	142.95
35	15.16	130	56.31	225	97.46	340	147.28
40	17.32	135	58.48	230	99.63	350	151.61
45	19.49	140	60.64	235	101.79	360	155.94
50	21.65	145	62.81	240	103.90	370	160.27
55	23.82	150	64.97	245	106.13	380	164.61
60	25.99	155	67.14	250	108.29	390	168.94
65	28.15	160	69.31	255	110.46	400	173.27
70	30.32	165	71.47	260	112.62	500	216.58
75	32.48	170	73.64	265	114.79	600	259.90
80	34.65	175	75.80	270	116.96	700	303.22
85	36.82	180	77.97	275	119.12	800	346.54
90	38.98	185	80.14	280	121.29	900	389.86
95	41.15	190	82.30	285	123.45	1000	433.18
100	43.31	195	84.47	290	125.62		

The fore bay leading to the flume should be made of such size that the velocity of water does not exceed 1½ feet per second, and

TABLE 8.

Riveted Hydraulic Pipe.

Diam. of Pipe in inches.	Area of Pipe in sq. inches.	Thickness of Iron by wire gauge.	Head in Feet the Pipe will safely stand.	Cu. ft. Water Pipe will convey per min. at vel. 3 ft. per sec.	Weight per lineal ft. in lbs.
3	7	18	400	9	2
4	12	18	350	16	2¼
4	12	16	525	16	3
5	20	18	325	25	3½
5	20	16	500	25	4¼
5	20	14	675	25	5
6	28	18	296	36	4¼
6	28	16	487	36	5¾
6	28	14	743	36	7½
7	38	18	254	50	5¼
7	38	16	419	50	6¾
7	38	14	640	50	8½
8	50	16	367	63	7½
8	50	14	560	63	9½
8	50	12	854	63	13
9	63	16	327	80	8½
9	63	14	499	80	10¾
9	63	12	761	80	14¼
10	78	16	295	100	9¼
10	78	14	450	100	11¾
10	78	12	687	100	15¾
10	78	11	754	100	17½
10	78	10	900	100	19½
11	95	16	269	120	9¾
11	95	14	412	120	13
11	95	12	626	120	17¼
11	95	11	687	120	18¾
11	95	10	820	120	21
12	113	16	246	142	11¼
12	113	14	377	142	14
12	113	12	574	142	18½
12	113	11	630	142	19¾
12	113	10	753	142	22¾
13	132	16	228	170	12
13	132	14	348	170	15
13	132	12	530	170	20
13	132	11	583	170	22
13	132	10	696	170	24½
14	153	16	211	200	13
14	153	14	324	200	16
14	153	12	494	200	21½
14	153	11	543	200	23½
14	153	10	648	200	26
15	176	16	197	225	13¾
15	176	14	302	225	17
15	176	12	460	225	23
15	176	11	507	225	24½
15	176	10	606	225	28
16	201	16	185	255	14½
16	201	14	283	255	17¼
16	201	12	432	255	24¼
16	201	11	474	255	26½

Riveted Hydraulic Pipe. (Continued.)

am. of Pipe in inches.	Area of Pipe in sq. inches.	Thickness of Iron by wire gauge.	Head in Feet the Pipe will safely stand.	Cu. ft. Water Pipe will convey per min. at vel. 3 ft. per sec.	Weight per lineal ft. in lbs
16	201	10	567	255	29½
18	254	16	165	320	16½
18	254	14	252	320	20½
18	254	12	385	320	27¼
18	254	11	424	320	30
18	254	10	505	320	34
20	314	16	148	400	18
20	314	14	227	400	22½
20	314	12	346	400	30
20	314	11	380	400	32½
20	314	10	456	400	36½
22	380	16	135	480	20
22	380	14	206	480	24¾
22	380	12	316	480	32¾
22	380	11	347	480	35¾
22	380	10	415	480	40
24	452	14	188	570	27¼
24	452	12	290	570	35½
24	452	11	318	570	39
24	452	10	379	570	43½
24	452	8	466	570	53
26	530	14	175	670	29¼
26	530	12	267	670	38½
26	530	11	294	670	42
26	530	10	352	670	37
26	530	8	432	670	57¼
28	615	14	102	775	31¼
28	615	12	247	775	41¼
28	615	11	273	775	45
28	615	10	327	775	50¼
28	615	8	400	775	61¼
30	706	12	231	890	44
30	706	11	254	890	48
30	706	10	304	890	54
30	706	8	375	890	65
30	706	7	425	890	74
36	1017	11	141	1300	58
36	1017	10	155	1300	67
36	1017	8	192	1300	78
36	1017	7	210	1300	88
40	1256	10	141	1600	71
40	1256	8	174	1600	86
40	1256	7	189	1600	97
40	1256	6	213	1600	108
40	1256	4	250	1600	126
42	1385	10	135	1760	74½
42	1385	8	165	1760	91
42	1385	7	180	1760	102
42	1385	6	210	1760	114
42	1385	4	240	1760	133
42	1385	¼	270	1760	137
42	1385	3	300	1760	145
42	1385	5/16	321	1760	177
42	1385	⅜	363	1760	216

it should be free from abrupt turns. The same applies to the tail race. The velocity of water in wooden flumes should not exceed 7 to 8 feet per second. Riveted steel pipe is used for the penstocks and for carrying water from considerable distances under high heads. In some locations it is buried, in others it is simply placed on the ground. Wooden-stave pipe is used to a large extent when the heads do not much exceed 200 feet. Table 7 gives the pressure of water at different heads, while Table 8 gives considerable data relating to riveted-steel hydraulic pipe.

Governors are required to keep the speed constant under change of load and change of head. Various governors are manufactured which give excellent satisfaction.

TABLE 9.

Horse Power per cubic foot of water per minute for different heads.

Heads in Feet.	Horse Power.	Heads in Feet.	Horse Power	Heads in Feet.	Horse Power.	Heads in Feet.	Horse Power.
1	.0016098	170	.273666	330	.531234	490	.788802
20	.032196	180	.289764	340	.547332	500	.804900
30	.048294	190	.305862	350	.563430	520	.837096
40	.064392	200	.321960	360	.579528	540	.869292
50	.080490	210	.338058	370	.595626	560	.901488
60	.096588	220	.354156	380	.611724	580	.933684
70	.112686	230	.370254	390	.627822	600	.965880
80	.128784	240	.386352	400	.643920	650	1.046370
90	.144892	250	.402450	410	.660018	700	1.126860
100	.160980	260	.418548	420	.676116	750	1.207350
110	.177078	270	.434646	430	.692214	800	1.287840
120	.193176	280	.450744	440	.708312	900	1.448820
130	.209274	290	.466842	450	.724410	1000	1.609800
140	.225372	300	.482940	460	.740508	1100	1.770780
150	.241470	310	.499038	470	.756606		
160	.257568	320	.515136	480	.772704		

GAS ENGINES.

There are at present, in the United States, several successful electrical installations using gas engines as prime movers, while they have been operated abroad for a greater length of time. The advantages for gas engines are given as follows:

1. **Minimum fuel and heat consumption.**
2. **Light-load efficiency is higher than for the steam engines.**
3. **Low cost of operation and maintenance.**

4. **Simplification of equipment and small number of auxiliaries.**
5. **No heat lost due to radiation when engines are idle.**
6. **Quick starting.**
7. **Extensions may be easily made.**
8. **High pressures are limited to the engine cylinders.**

Fig. 12 shows the efficiency and amount of gas consumed by a 550 H.P. engine, Pittsburg natural gas being used.

The only auxiliaries needed are the igniter generators and the air compressors, with a pump for the jacket water in some cases. These may be driven by a motor or by a separate gas engine. The jacket water may be utilized for heating purposes in many plants. Cooling towers may be installed where water is scarce.

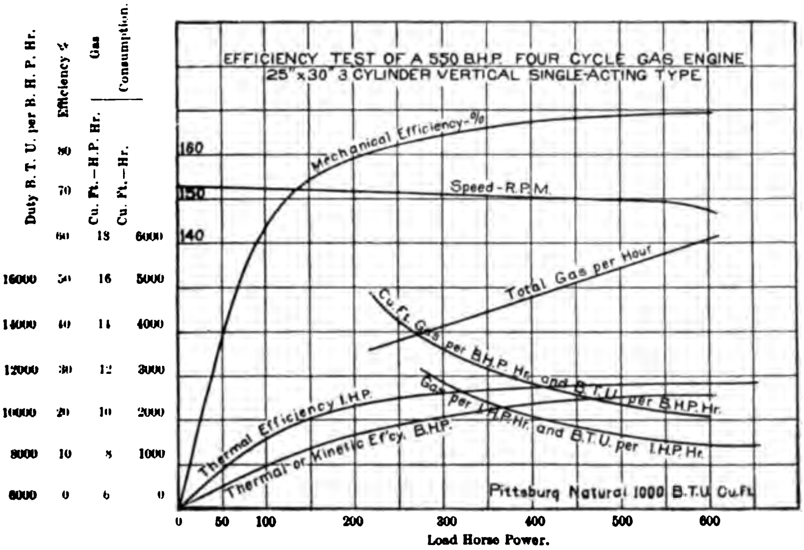


Fig. 12.

Parallel operation of alternators when direct-driven by gas engines has been successful, a spring coupling being used between the engines and generators in some cases to absorb the variation in angular velocity.

The fact that no losses occur, due to heat radiation when the machines are not running, and the lack of losses in piping, add greatly to the plant efficiency. If producer gas or blast furnace gas is used, a larger engine must be installed, to give the sa power, than when natural or ordinary coal gas is used.

stations are often combined with gas works, and gas engines can be installed in such stations to particular advantage in many cases.

THE ELECTRICAL PLANT.

GENERATORS.

The first thing to be considered in the electrical plant is the generators, after which the auxiliary apparatus in the way of exciters, controlling switches, safety devices, etc., will be taken up. A general rule which, by the way, applies to almost all machinery for power stations is to select apparatus which is considered as "standard" by the manufacturing companies. This rule should be followed for two reasons. First, reliable companies employ men who may be considered as experts in the design of their machines, and their best designs are the ones which are standardized. Second, standard apparatus is from 15 to 25% cheaper than semi-standard or special work, owing to larger production, and it can be furnished on much shorter notice. Again, repair parts are more cheaply and readily obtained.

Specifications should call for performance, and details should be left, to a very large extent, to the manufacturers. Following are some of the matters which may be incorporated in the specifications for generators:

1. Type and general characteristics.
2. Capacity and overload with heating limits.
3. Commercial efficiency at various loads.
4. Excitation.
5. Speed and regulation.
6. Floor space.
7. Mechanical features.

As to the type of machine, this will be determined by the system selected. They may be direct-current, alternating-current, single or polyphase, or as in some plants now in operation, they may be double-current generators. The voltage, compounding, frequency, etc., should be stated. Direct-current machines are seldom wound for a voltage above 600, but alternating-current generators may be purchased which will give as high as 15,000 volts at the terminals. As a rule it is well not to use an extremely high voltage for the generators themselves, but to use step-up transformers in case a very high line voltage is necessary. Up to about 7,000 volts generators may be safely used directly on the line.

Above this local conditions will decide whether to connect the machine directly to the line or to step up the voltage. Machines wound for high potential are more expensive for the same capacity and efficiency, but the cost of step-up transformers and the losses in the same are saved by using such machines, so that there is a slight gain in efficiency which may be utilized in better regulation of the system, or in lighter construction of the line. On the other hand, lightning troubles are liable to be aggravated when transformers are not used, as the transformers act as additional protection to the machines, and if the transformers are injured they may be more readily repaired or replaced.

The following voltages are considered standard:

Direct-current generators 125, 250, 550–600.

Alternating-current systems, high pressure, 2,200, 6,000, 10,000, 15,000, 20,000, 30,000, 40,000, 60,000.

The generators, with transformers when used, should be capable of giving a no-load voltage 10% in excess of these figures. 25 and 60 cycles are considered as standard frequencies, the former being more desirable for railway work and the latter for lighting purposes.

The size of machines to be chosen has been briefly considered. Alternators are rated for non-inductive load or a power factor of unity. Aside from the overload capacity to be counted upon as reserve, the Standardization Report of the American Institute of Electrical Engineers recommends the following for the heating limits and overload capacity of generators:

Maximum values of temperature elevation,
Field and armature, by resistance, 50° C.
Commutator and collector rings and brushes, by thermometer, 55° C.
Bearings and other parts of machine, by thermometer, 40° C.

Overload capacity should be 25% for two hours, with a temperature rise not to exceed 15° above full load values, the machine to be at constant temperature reached under normal load, before the overload is applied. A momentary overload of 50% should be permissible without excessive sparking or injury. Some companies recommend an overload capacity of 50% for two hours when the machines are to be used for railway purposes.

As a rule, generators should have a high efficiency over a considerable range of load, although the nature of the load will have much to do with this. It is always desirable that maximum efficiency be as high as is compatible with economic investment.

Table 10 gives reasonable efficiencies which may be expected for generating apparatus. In order to arrive at what may be considered the best maximum efficiency to be chosen, the cost of power generation must be known, or estimated, and the fixed charges on capital invested must also be a known quantity. From the cost of power, the saving on each per cent increase in efficiency can be determined, and this should be compared with the charges on the additional investment necessary to secure this increased efficiency. A certain point will be found where the sum of the two will be a minimum.

If a generator is to be run for a considerable time at light loads, one with low "no-load" losses should be chosen. These losses are not rigidly fixed but they vary slightly with change of load. It is the same question of "all-day efficiency" which is treated, in the case of transformers, in "Power Transmission". Under no-load losses may be considered, in shunt-wound generators, friction losses, core losses, and shunt-field losses. I^2R losses in the series field, in the armature, and in the brushes, vary as the square of the load.

Table 10.

Average Maximum Efficiencies.

K.W.	Per Cent
5	85
10	88
25	90
50	92
150	93
200	94
500	95
1000	96

Dynamos, if for direct current, may be self-excited, shunt- or compound-wound, or separately excited. Separate excitation is not recommended for these machines. Alternators require separate excitation, though they may be compounded by using a portion of e armature current when rectified by a commutator. Automatic ulation of voltage is always desirable, hence the general use of compound-wound machines for direct currents. Many alternators using rectified currents in series fields for keeping the voltage nearly constant are in service in small plants as well as several of the so-called "compensated" alternators, arranged with special devices which maintain the same compounding with different power factors. The latter machine gives good satisfaction if properly cared for, but an automatic regulator, governed by the generator voltage and current, which acts directly on the exciter field, is taking its place. The capacity of the exciters must be such that they will furnish sufficient excitation to maintain normal voltage at the terminals of the generators when running at 50% overload. Table 11 gives the proper capacity of exciter for the generator listed.

TABLE 11.

Exciters for Single-Phase Alternating-Current Generators.

60 Cycles.

Alternator Classification.			Exciter Classification.		
Poles.	K.W.	Speed.	Poles.	K.W.	Speed.
8 -	60 -	900	2 -	1.5 -	1900
8 -	90 -	900	2 -	1.5 -	1900
8 -	120 -	900	2 -	1.5 -	1900
12 -	180 -	600	2 -	2.5 -	1900
16 -	300 -	450	2 -	4.5 -	1800

If direct-connected, the speeds of the generators will be determined by the prime mover selected. If belt-driven, small machines may be run at a high speed, as high-speed machines are cheaper than slow- or moderate-speed generators. In large sizes, this saving is not so great.

When shunt-wound dynamos are used, the inherent regulation should not exceed 2 to 3% for large machines. For alternators, this is much greater and depends on the power factor of the load. A fair value for the regulation of alternators on non-inductive load is 10 per cent.

Exciters may be either direct-connected or belted to the shaft of the machine which they excite, or they may be separately driven. They are usually compound-wound and furnish current at 125 or 250 volts. Separately driven exciters are preferred for most plants as they furnish a more flexible system, and any drop in the speed of the generator does not affect the exciter voltage. Ample reserve capacity of exciters should be installed, and in some cases storage batteries, used in conjunction with exciters, are recommended in order to insure reliability of service.

Motor-generator sets, boosters, frequency changers, and other rotating devices come under the head of special apparatus and are governed by the same general rules as generators.

Transformers for stepping the voltage from that generated by the machine up to the desired line voltage, or *vice versa*, at the substation, may be of three general types, according to the method of cooling. Large transformers require artificial means of cooling, if they are not to be too bulky and expensive. They may be air-cooled, oil-cooled, or water-cooled.

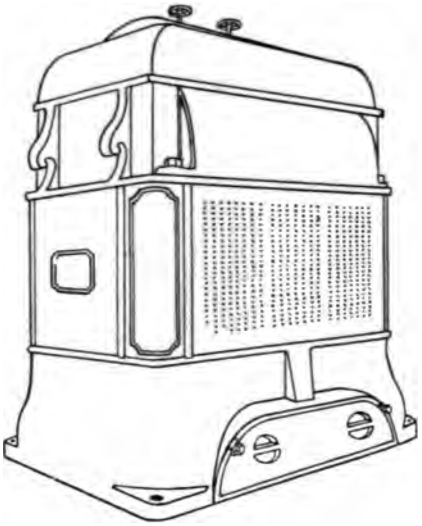


Fig. 13.

Air-cooled transformers are usually mounted over an air-tight pit fitted with one or more motor-driven blowers which feed into the pit. The transformer coils are subdivided so that no part of the winding is at a great distance from air and the iron is provided with ducts. Separate dampers control the amount of air which passes between the coils or through the iron. Such transformers give good satisfaction for voltages up to 20,000 or higher, and can be built for any capacity. Care must be taken to see that there is no liability of the air supply failing, as the capacity of the transformers is greatly reduced when not supplied with air. Fig. 13 shows a three-phase air-blast transformer.

Oil-cooled transformers have their cores and windings placed in a large tank filled with oil. The oil serves to conduct the heat to the case, and the case is usually either made of corrugated sheet metal or of cast iron containing deep grooves, so as to increase the radiating surface. These transformers do not require such heavy insulation on the outside of the coils as air-blast machines because the oil serves this purpose. Simple oil-cooled transformers are seldom built for capacities exceeding 250 K.W. as they become too bulky, but they are employed for the highest voltages now in use. Fig. 14 shows a transformer of this type.

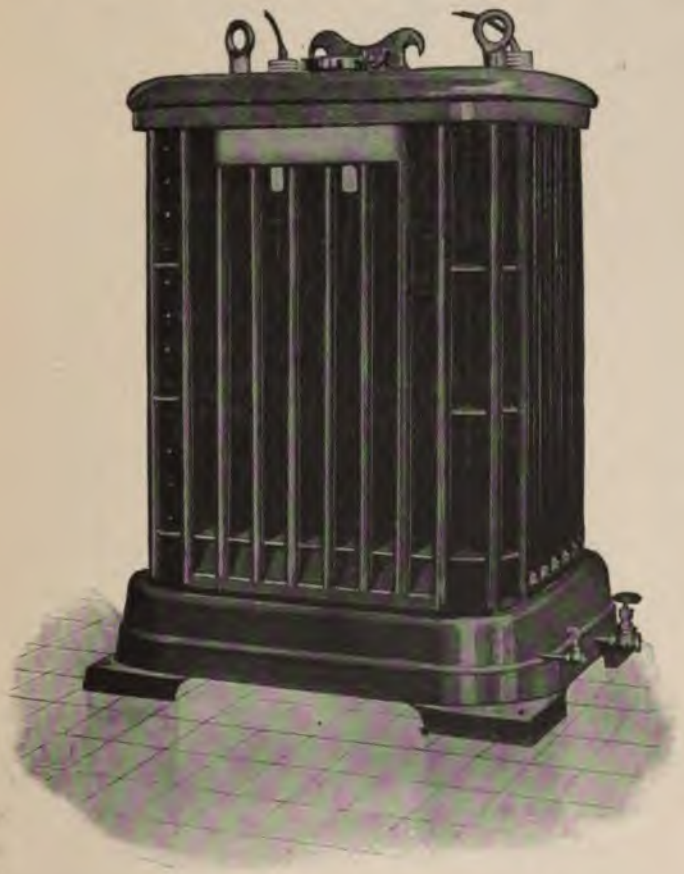


Fig. 14. 150 K.W. Self-Cooled Oil Transformer.

Water-cooled transformers. When large transformers for high voltages are required, the water-cooled type is usually selected. This type is similar to an oil-cooled transformer, but with water tubes arranged in coils in the top. Cold water passes through these tubes and aids in removing heat from the oil. Some types have the low-tension windings made up of tubes through which the water circulates. Water-cooled transformers must not have

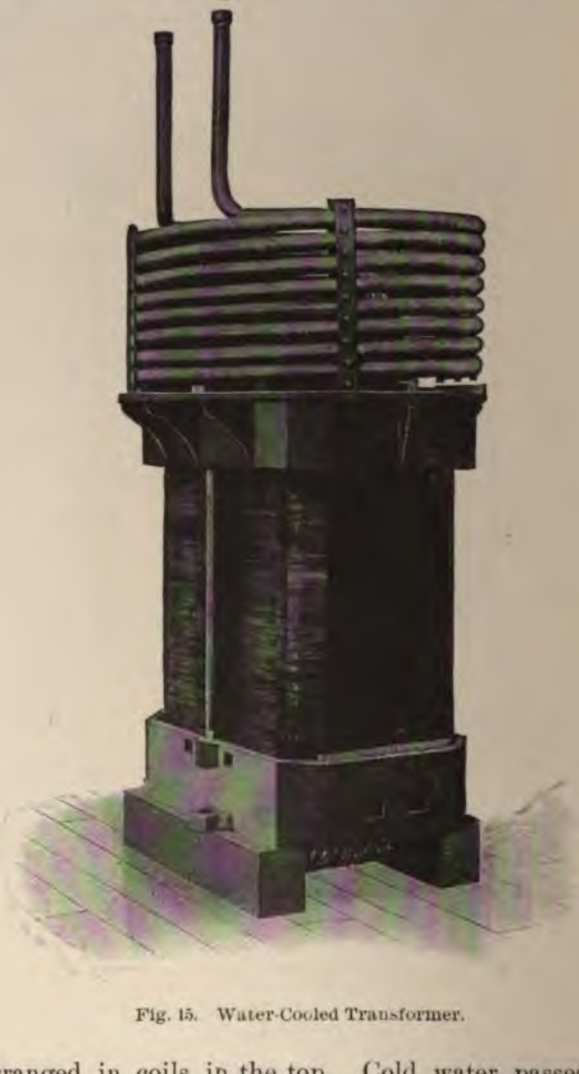


Fig. 15. Water-Cooled Transformer.

the supply of cooling water shut off for any length of time when under normal load or they will overheat. Fig. 15 shows a water-cooled transformer.

For connections of transformers, see "Power Transmission".

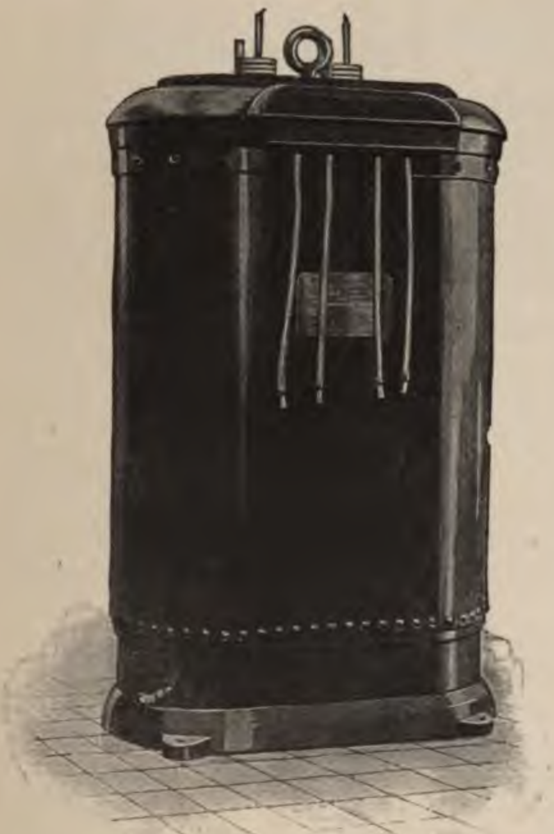
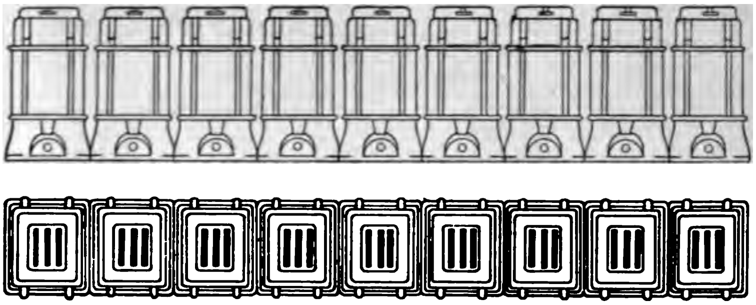


Fig. 15. 400 K.W. Water Cooled Oil Transformer.

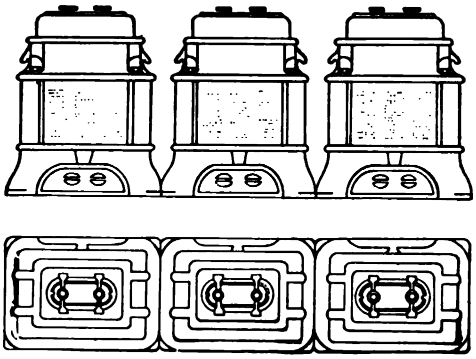
One or more spare transformers should always be on hand and they should be arranged so that they can be put into service on very short notice.

Three-phase transformers allow a considerable saving in floor space, as can be seen by referring to Fig. 16; they are cheaper than three separate transformers which make up the same capacity, but they are not as flexible as a single-phase transformer and one complete unit must be held for a reserve or "spare" transformer.

Storage Batteries. The use of storage batteries for central stations and substations is clearly outlined in "Storage Batteries". The chief points of advantage may be enumerated as follows:



Single-Phase Air-Blast Transformers. Total Capacity 8,000 K.W.



Three-Phase Air-Blast Transformers. Total Capacity 8,000 K.W.

Fig. 16.

1. Reduction in fuel consumption due to the generating machinery being run at its greatest economy.
2. Better voltage regulation.
3. Increased reserve capacity and less liability to interruption of service.

The main disadvantage is the high cost.

Switchboards. The switchboard is the most vital part of the whole system of supply, and should receive consideration as such. Its objects are: to collect the energy as supplied by the generators and direct it to the desired feeders, either overhead or under ground; furnish a support for the various measuring instruments connected in service, as well as the safety devices for the protection of the generating apparatus; and control the pressure of the supply. Some of the essential features of all switchboards are:

1. The apparatus and supports must be fire-proof.
2. The conducting parts must not overheat.
3. Parts must be easily accessible.
4. Live parts except for low potentials must not be placed on the ront of the operating panels.
5. The arrangement of circuits must be symmetrical and as simple as it is convenient to make them.
6. Apparatus must be arranged so that it is impossible to make a wrong connection that would lead to serious results.
7. It should be arranged so that extensions may be readily made.

There are two general types—in the first, all of the switching and indicating apparatus is mounted directly on panels, and in the second, the current-carrying parts are at some distance from the panels, the switches being controlled by long connecting rods; operated electrically or by means of compressed air. The first may again be divided into direct-current and alternating-current switchboards. It is from the first class of apparatus that the switchboard gets its name and the term is still applied, even when the board proper forms the smallest part of the equipment. Switchboards have been standardized to the extent that standard generator, exciter, feeder, and motor panels may be purchased for certain classes of work, but the vast majority of them are made up as semi-standard or special.

The leads which carry the current from the machines to the switches should be put in with very careful consideration. Their size should be such that they will not heat excessively when carrying the rated overload of the machine, and they should preferably be placed in fire-proof ducts, although low-potential leads do not always require this construction. Curves showing sizes for lead-covered cables for different currents are given in "Power Transmission". Table 12 gives standard sizes of wires and cables together with the thickness of insulation necessary for different voltages. Cables should be kept separate as far as possible so that if a fault does occur on one cable, neighboring conductors will not be injured. For lamp and instrument wiring, such as leads to potential and current transformers, the following sizes of wire are recommended:

No. 16 or No. 14, wiring to lamp sockets.

No. 12 wire, $\frac{3}{64}$" rubber insulation, all other small wiring under 600 volts potential.

No. 12, $\frac{3}{32}$" rubber insulation for primaries of potential transformers from 600 to 3,500 volts.

No. 8, $\frac{5}{32}$" rubber insulation for primaries of potential transformers up to 6,600 volts.

No. 8, $\frac{7}{32}$ rubber insulation for primaries of potential transformers up to 10,000 volts.

No. 4, $\frac{9}{32}$ rubber insulation for primaries of potential transformers up to 15,000 volts.

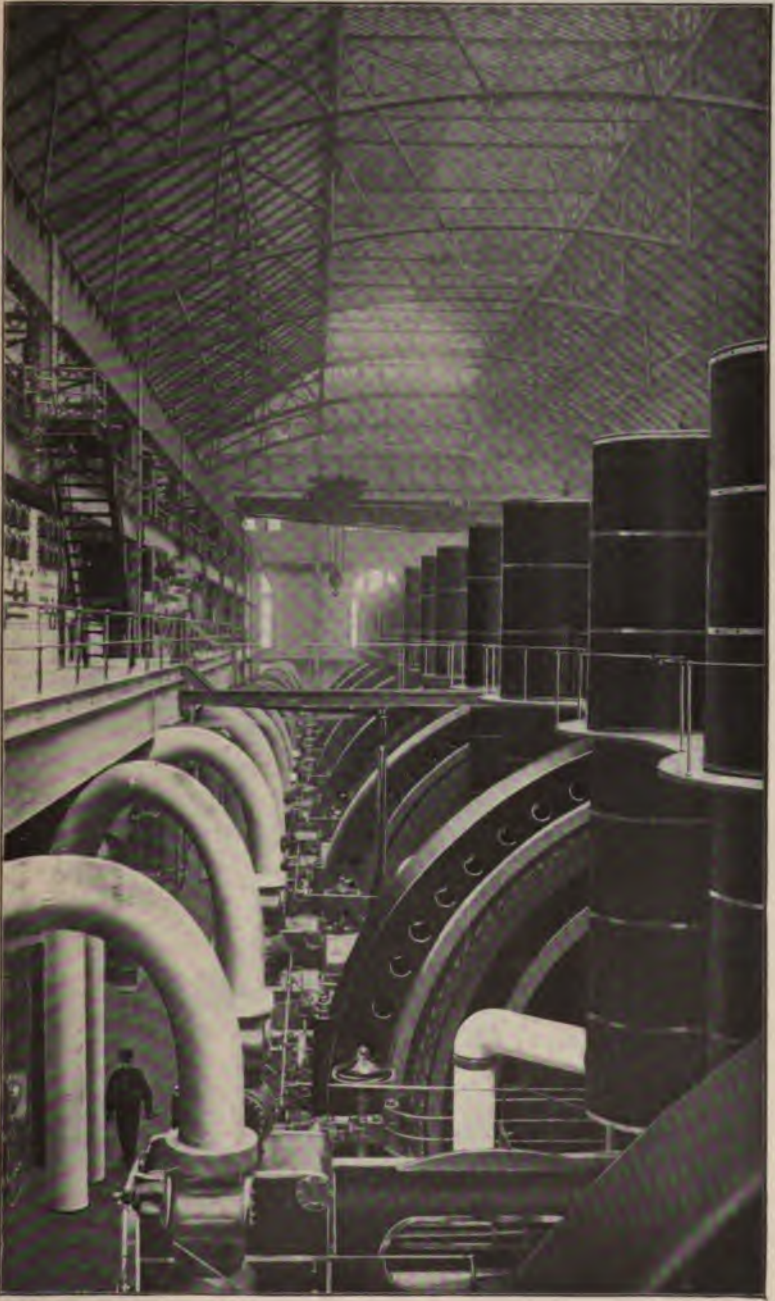
No. 4, $\frac{11}{32}$ rubber insulation for primaries of potential transformers up to 20,000 volts.

No. 4, $\frac{13}{32}$ rubber insulation for primaries of potential transformers up to 25,000 volts.

Where high-tension cables leave their metallic shields they are liable to puncture, so that the sheath should be flared out at this point and the insulation increased by the addition of compound. Fig. 17 shows such cable bells, as they are called, as recommended by the General Electric Company.

Central-station switchboards are usually constructed of panels about 90 inches high, from 16 inches to 36 inches wide, and $1\frac{1}{2}$ inches to 2 inches thick. Such panels are made of Blue Vermont, Pink Tennessee, or White Italian marble, or of black enameled slate. Slate is not recommended for voltages exceeding 1,100. The panels are in two parts, the sub-base being from 24 to 28 inches high. They are polished on the front and the edges are beveled. Angle and tee bars, together with foot irons and tie rods, form the supports for such panels, and on these panels are mounted the instruments, main switches, or controlling apparatus for the main switches, as the case may be, together with relays and hand wheels for rheostats and regulators. Small panels are sometimes mounted on pipe supports.

The usual arrangement of the panels is to have a separate panel for each generator, exciter, and feeder, together with what is known as a station or total-output panel. In order to facilitate extensions and simplify connections, the feeder panels are located



MANHATTAN 74th ST. POWER STATION, NEW YORK.
Showing Carey's Carbonate of Magnesia Pipe Coverings. Steam Connections.

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at one end of the board and the generator panels are placed at the other end, and the total-output panel between the two. The main bus bars extend throughout the length of the generator and feeder panels, and the desired connections are readily made. The instruments required are very numerous and a brief description only of a few of the more important can be given here.

TABLE 12.

Standard Wire and Cable.

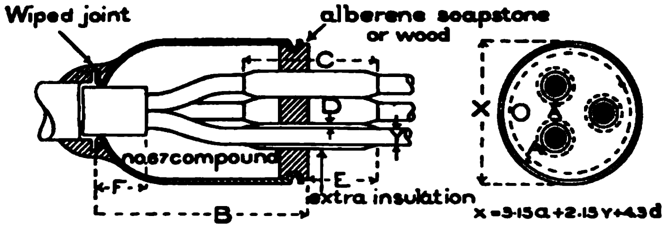
Wire (Solid).

Area.	Diam. Inches.	Terminal Drillings.	Amps.	Thickness of Rubber Insulation.							Gauge.
Circular Mils.	Bare.		Con. Current Capacity.	Volts 600	3500	6000	10000	15000	20000	25000	B. & S
				Special Insulation.							
2,582	.051	No. 30 Dr.	4								16
4,106	.064	30 "	6	3/64							14
6,530	.081	30 "	10	3/64	3/32						12
16,510	.128	18 "	25	3/64	3/32	5/32	7/32				8
26,251	.162	5 "	40	1/16							6
41,743	.204	1/4 "	60	1/16	3/32	5/32	7/32	21/64	14/32	17/32	4
66,373	.257	5/16 "	90	1/16							2
83,695	.289	11/32 "	110	5/64							1
105,593	.325	3/8 "	130	5/64	3/32	5/32	7/32	21/64	14/32	17/32	0
133,079	.365	7/16 "	170	5/64							00
167,805	.410	15/32 "	205	5/64							000
211,600	.460	17/32 "	250	5/64	3/32	5/32	7/32	21/64	14/32	17/32	0000

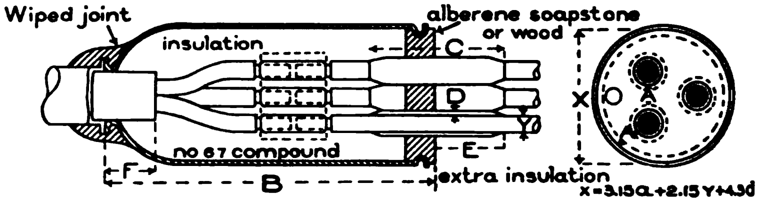
Cable.

(Stranded.)

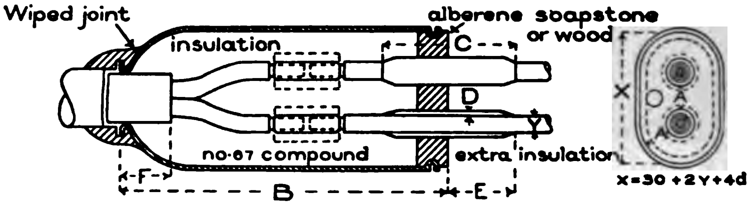
Circular Mils.	Diameter. Inches Bare.	Terminal Drilling	Con. Curr. Capacity. Amps.	Thickness of Rubber Insulation. (For 6000 V. only.)
250,000	.568	5/8'	290	3/32
300,000	.637	23/32"	340	3/32
350,000	.680	3/4"	380	3/32
400,000	.735	13/16"	420	3/32
500,000	.820	29/32"	500	3/32
600,000	.900	1"	575	7/64
800,000	1.037	1 1/8"	710	7/64
1,000,000	1.157	1 1/4"	830	7/64
1,500,000	1.412	1 1/2"	1100	1/8
2,000,000	1.65	1 3/4"	1350	1/4



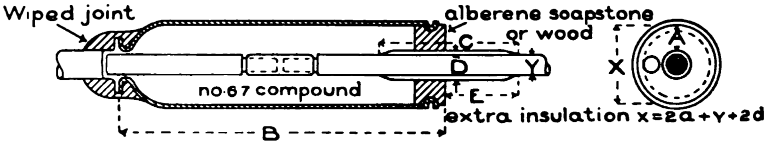
Three-Conductor Cable Without Joints.



Three-Conductor Cable With Joints.



Two-Conductor Cable With Joints.



Single-Conductor Cable With Joints.

VOLTS.	A	B	C	D	E	F
6600	1	12	5	⅛	2½	1
13200	1½	15	8	¼	4	2
26400	2	19	14	½	7	4

$\frac{1}{8}$-inch Lead or $\frac{1}{16}$-inch Brass Bells.

Fig. 17.

For direct current generator panels there are usually required:

1 Main switch.
1 Field switch.
1 Ammeter.
1 Voltmeter.
1 Field rheostat with controlling mechanism.
1 Circuit breaker
Bus bars and various connections.

These may be arranged in any suitable order, the circuit breaker being preferably located at the top so that any arcing which may occur will not injure other instruments. Fig. 18 gives a wiring diagram of such a panel.

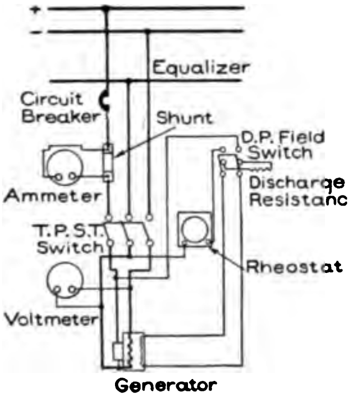


Fig. 18.

The main switch may be single or double throw, depending on whether one or two sets of bus bars are used. It may be triple pole as shown in Fig. 18, in which the middle bar serves as the equalizing switch, or the equalizing switch may be mounted on a pedestal near the machine, in which case the generator switch would be double-pole.

The field switch for large machines should be double-pole fitted with carbon breaks and arranged with a discharge resistance consisting of a resistance which is thrown across the terminals of the field just before the main circuit is opened. One voltmeter located on a swinging bracket at the end of the panel, and arranged so that it can be thrown across any machine or across the bus bars by means of a dial switch, is sometimes used, but it is preferable to have a separate meter for each generator.

Small rheostats are mounted on the back of the panel, but large ones are chain operated and preferably located below the floor, the controlling hand wheel being mounted on the panel.

The circuit breaker may be of the carbon break or the magnetic blow-out type. Fig. 19 shows circuit breakers of both types. Lighting panels for low potentials are often fitted with fuses instead of circuit breakers, in which case they may be open fuses on the back of the panel or enclosed fuses on either the front or back of the panel.

Direct-Current feeder panels contain:

1 Ammeter.
1 Circuit Breaker.
1 or more main switches, single-pole, and single- or double-throw.
1 recording wattmeter, not always used
Apparatus for controlling regulators when such are used.

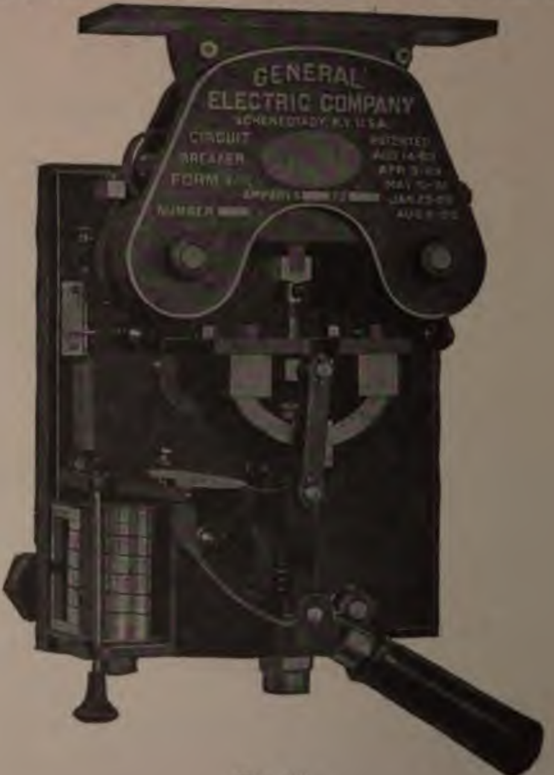


Fig. 19.

One voltmeter usually serves for several feeder panels, such a meter being mounted above the panels or on a swinging bracket at the end. Switches should preferably be of the quick-break type. Fig. 20 shows some standard railway feeder panels.

Exciter Panels are nothing more than generator panels on a small scale.

Total Output Panels contain instruments recording the total power delivered by the plant to the switchboard. Alternating-current panels for potentials up to 1,100 volts follow the same general construction. Synchronizing devices are necessary on the generator panels, and additional ammeters are used for polyphase boards. Sometimes the exciter and generator panels are combined in one. Fig. 21 shows such a combination. The same construction is sometimes used for voltages up to 2,500, though it is not usually recommended. The paralleling of alternators is treated in "Management of Dynamo Electric Machinery".

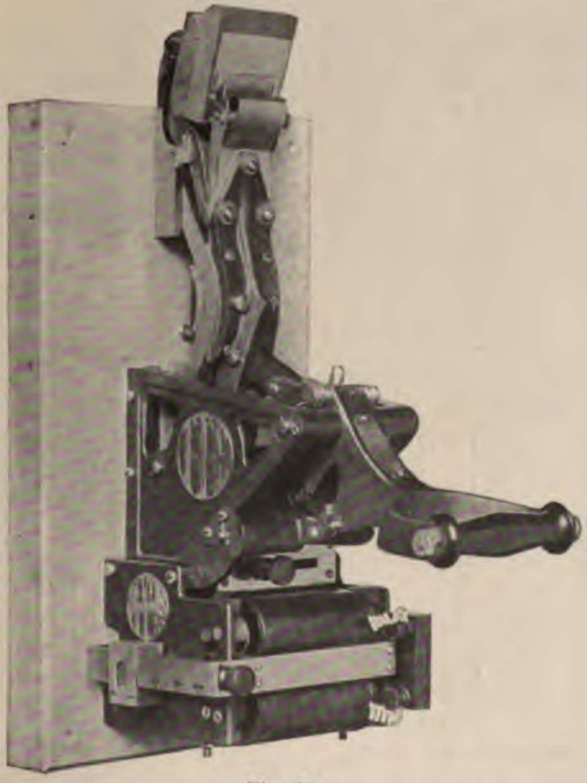


Fig. 19.

For the higher voltages, the measuring instruments are no longer connected directly in the circuit, and the main switch is not mounted directly on the panel. Current and potential transformers are used for connecting to the indicating voltmeters and ammeters, and the recording wattmeters and potential transformers are used for the synchronizing device. These transformers are mounted at some distance from the panel, while the switches may be located near the panel and operated by a system of levers, or they may be located at considerable distance and operated by electricity or by compressed air.

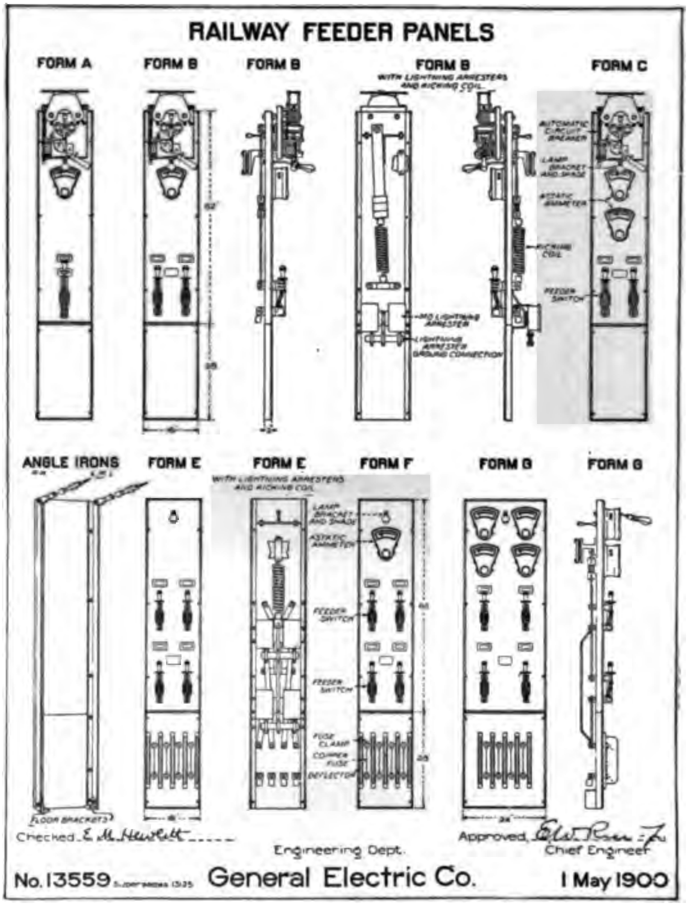
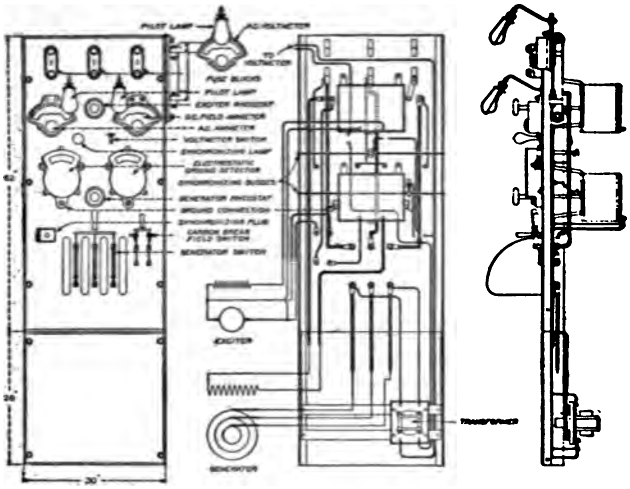


Fig. 20.

Oil Switches are recommended for all high potential work for the following reasons: By their use it is possible to open circuits of higher potential and carrying greater currents than with any other type of switch. They may be made quite compact. They may readily be made automatic and thus serve as circuit breakers for the protection of machines and circuits when overloaded.

SWITCHBOARD PANEL FOR
ONE THREE-PHASE ALTERNATING CURRENT GENERATOR
TO 2500 VOLTS



CLASSIFICATION

Type	Volts	Amperes	Form	Switch	Field Ammeter	Synchronizing Device
A T 6	2500	130	A 1	S.T	with	with
A T 6	2500	130	A 2	S T	with	without
A T 6	2500	130	A 3	S.T.	without	with
A T 6	2500	130	A 4	S.T	without	without
A T 6	2500	130	A 5	D T	with	without
A T 6	2500	130	A 6	D.T.	without	without

Transformer is calibrated with Voltmeter only. Therefore Synchronizing Plug must be removed for correct Voltmeter reading

Fig. 21.

There are several types on the market. One constructed for three-phase work, to be closed by hand and to be electrically tripped or opened by hand, is shown in Fig. 22. This shows the switch without the can containing the oil. Fig. 23 shows a similar switch hand-operated, with the can in place. Both of these switches are arranged to be mounted on the panel. Fig. 24 shows how the same switches are mounted when placed at some distance from the panel. For high voltages, they are placed in brick cells and often three separate single-pole switches are used, each placed in a separate cell so that injury to the contacts in one leg will in no way affect the other parts of the switch. A form of oil switch used for the very highest potentials and currents met with in practice, is shown in Fig. 25. This particular switch is operated by means of an electric motor, though it may be as readily arranged to operate by means of a solenoid or by compressed air. General practice is to place all high-tension bus bars and circuits in separate compartments formed by brick or cement, and duplicate bus bars are quite common.

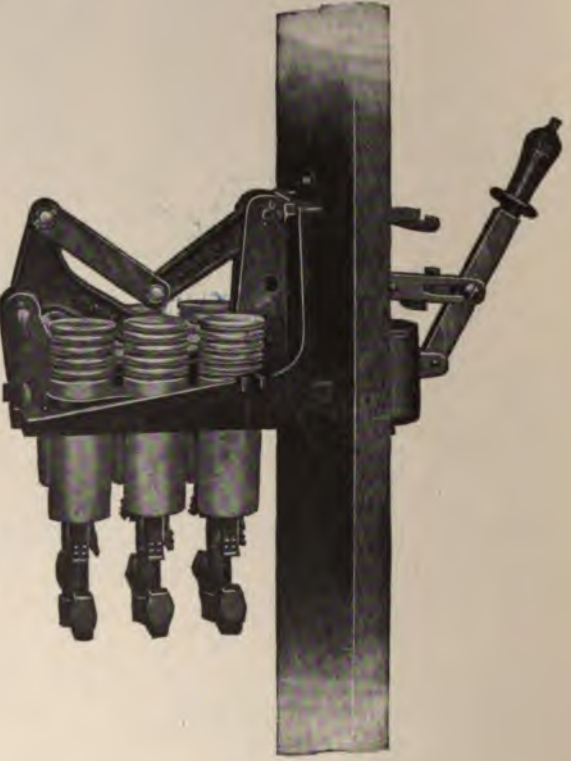


Fig. 22.

Oil switches are made automatic by means of tripping magnets, which are connected in the secondary circuits of current transformers, or they may be operated by means of relays fed from the secondaries of current transformers in the main leads. Such relays are made very compact and can be mounted on the

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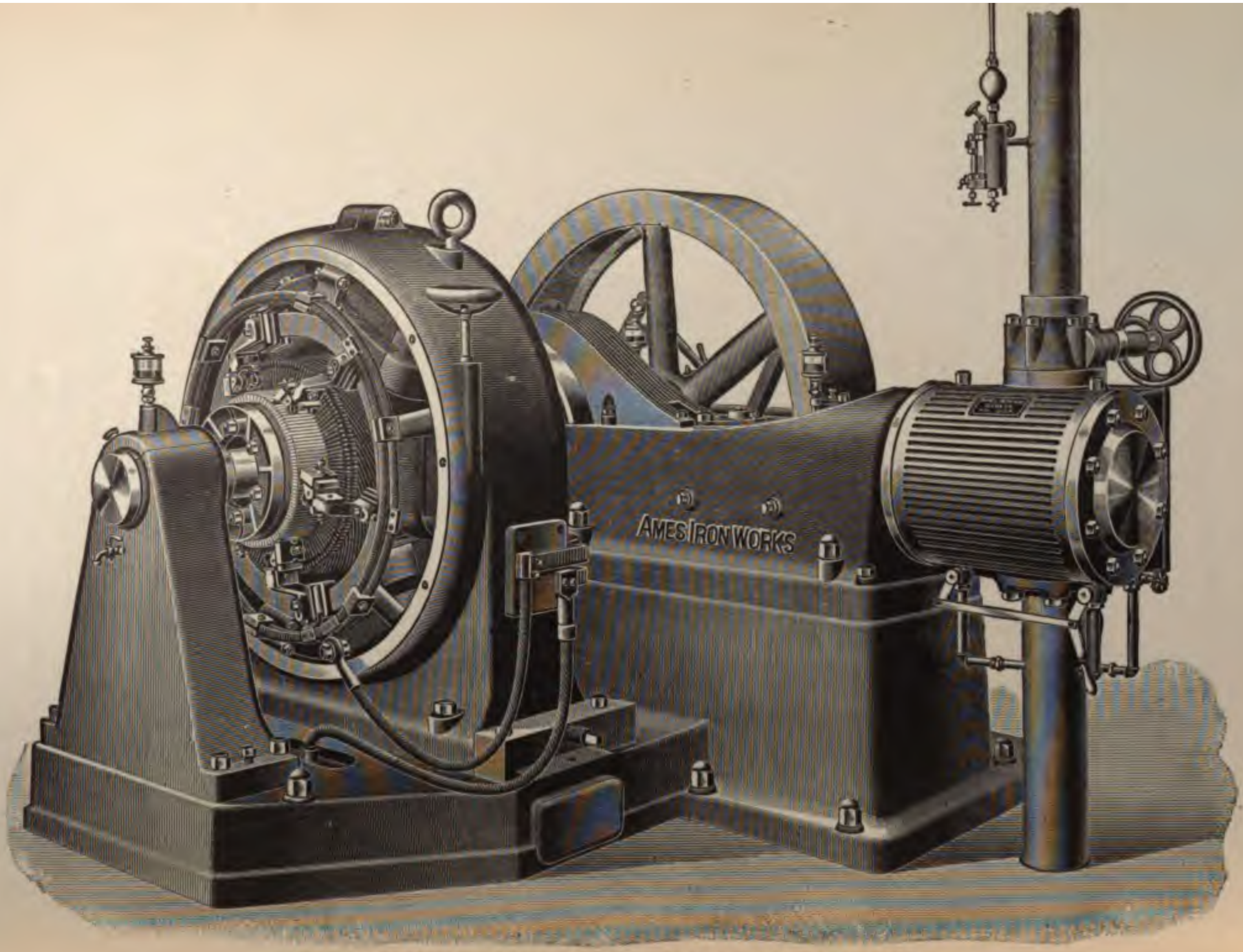


ENGINE DIRECT-CONNECTED WITH WESTINGHOUSE GENERATOR.

front or back of the switchboard panels. The wiring of such tripping devices is shown in Fig. 26.

With remote control of switches, the switchboard becomes in many instances more properly a switch house, a separate building being devoted to the bus bars, switches, and connections. In other cases a framework of angle bars or gas pipe is made for the support of the switches, bus bars, current and potential transformers, etc.

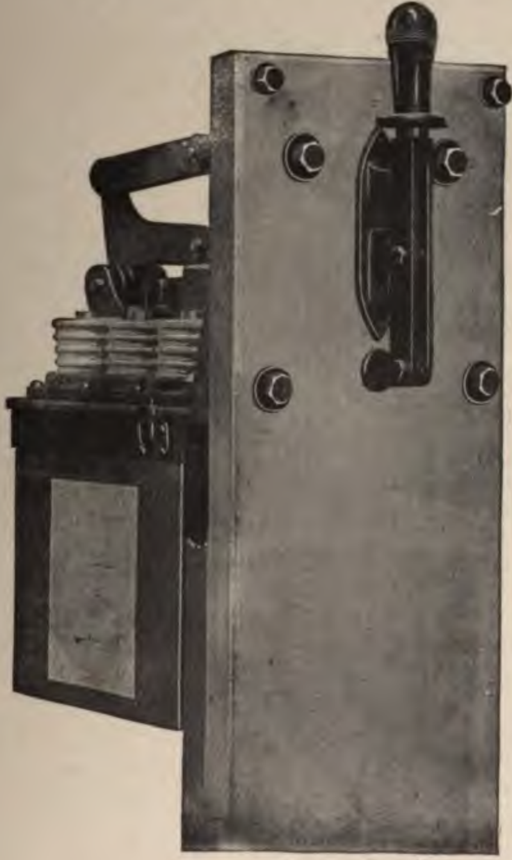
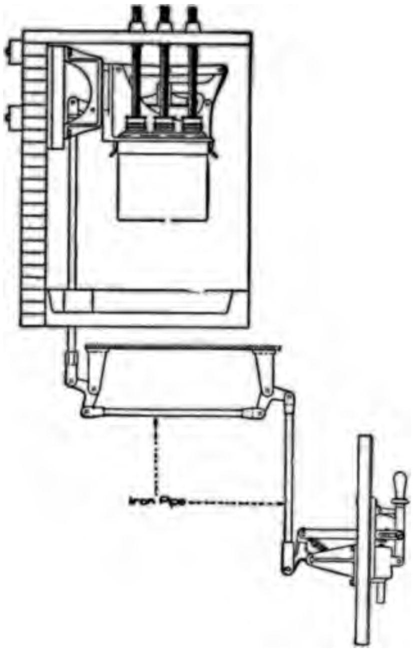
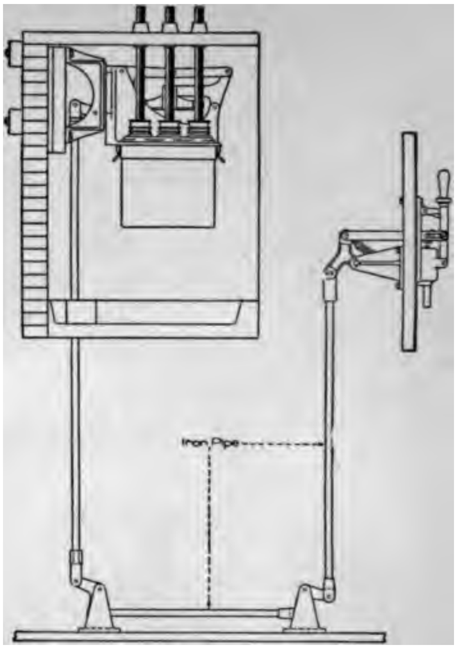


Fig. 23.

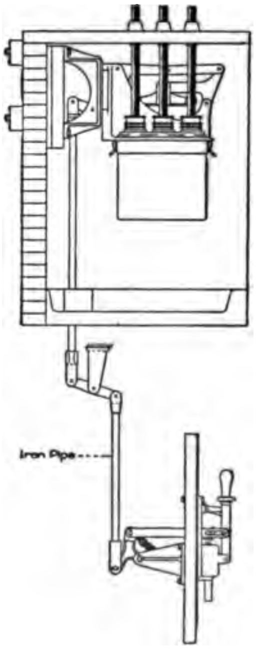
Additional types of panels which may be mentioned are transformer panels, usually containing switching apparatus only; rotary converter panels for both the alternating-current and direct-current sides; induction-motor panels and arc-board panels. The latter



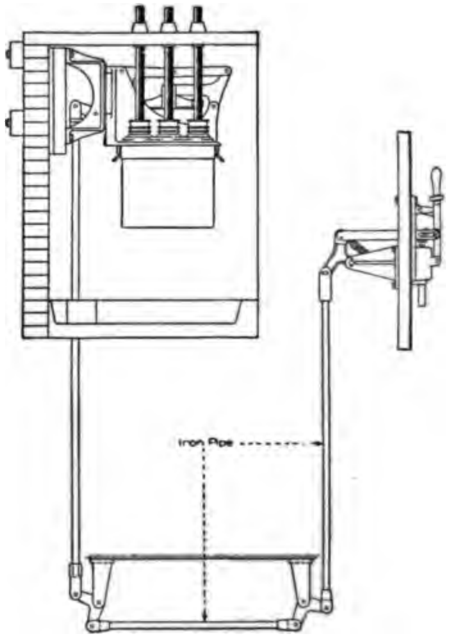
Form K Oil Switches Located Above and Back of Operating Panel.



Form K Oil Switches Located Below and Back of Operating Panel.



Form K Oil Switches Located Above Operating Panel.



Form K Oil Switches Located Back of Operating Panel.

Fig. 24.

are arranged to operate with plug switches. A single panel used in the operation of series transformers on arc-lighting circuits is shown in Fig. 27.

Safety Devices. In addition to the ordinary overload tripping devices which have already been considered, there are various safety devices necessary in connection with the operation of central stations. One of the most important of these is the *lightning arrester*. For direct-current work, the lightning arrester takes the form of a single gap connected in series with a high resistance and fitted with some device for destroying the arc formed by discharge to the ground. One of these is connected between either side of the circuit and the ground, as shown diagrammatically in Fig. 28. A "kicking" coil is connected in circuit between the arresters and the machine to be protected, to aid in forcing the lightning discharge across the gap. In railway feeder panels such kicking coils are mounted on the backs of the panels.

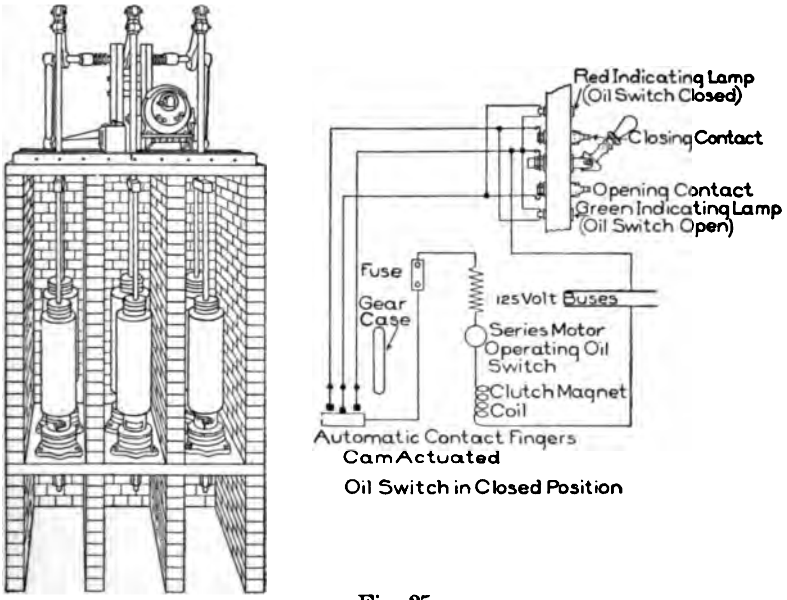


Fig. 25.

For alternating-current work, several gaps are arranged in series, these gaps being formed between cylinders of "non-arcing" metal. High resistances and reactance coils are used with these,

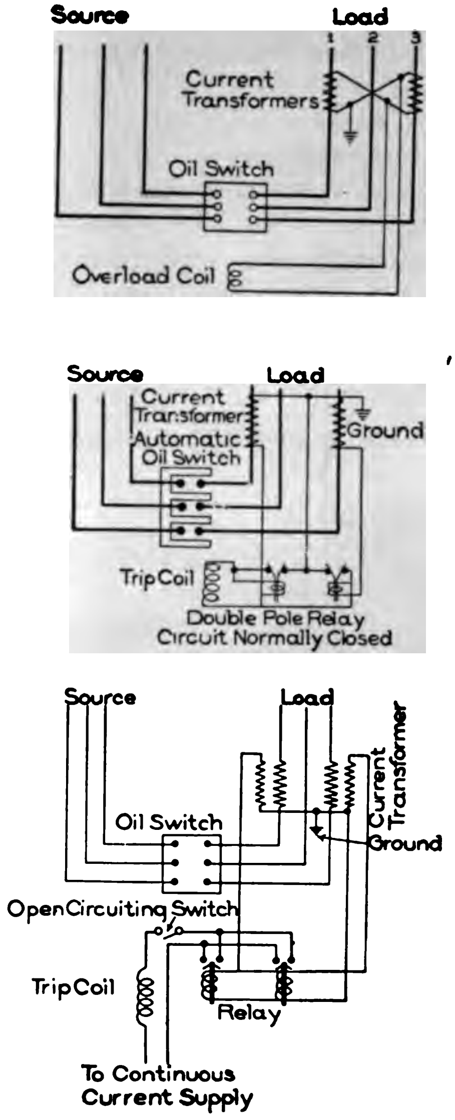


Fig. 26.

as in direct-current arresters. Fig. 29 shows connections for a 10,000-volt lightning arrester. Lighting arresters should always be provided with knife blade switches so that they can be disconnected from the circuit for inspection and repairs. A typical installation of lightning arresters is shown in Fig. 30.

Reverse-current relays are installed when machines or lines are operated in parallel. If two or more alternators are running and connected to the same set of bus bars, and one of these should fail to generate voltage by the opening of the field circuit, or some other cause, the other machine would feed into this generator and might cause considerable damage before the current flowing would be sufficient to operate the circuit breaker by means of the overload trip coils. To avoid this, reverse-current relays are used. They are so arranged as to operate at say ¼ the normal current of the machine or line, but to operate only when the power is being delivered in the wrong direction.

Speed-limit devices are used on both engines and rotary converters to prevent racing in the one case and running away in the second. Such devices act on the steam supply of engines and on the direct-current circuit breakers of rotary converters, respectively.

Complete wiring diagram for a railway switchboard is shown in Fig. 31.

Substations. Substations are for the purpose of transforming the high potentials down to such potentials as can be used on motors or lamps, and in many cases to convert alternating current into direct current. Step-down transformers do not differ in any respect from step-up transformers. Either motor-generator sets or rotary converters may be used to change from alternating to direct current. The former consist of synchronous or induction motors, direct connected to direct-current generators, mounted on

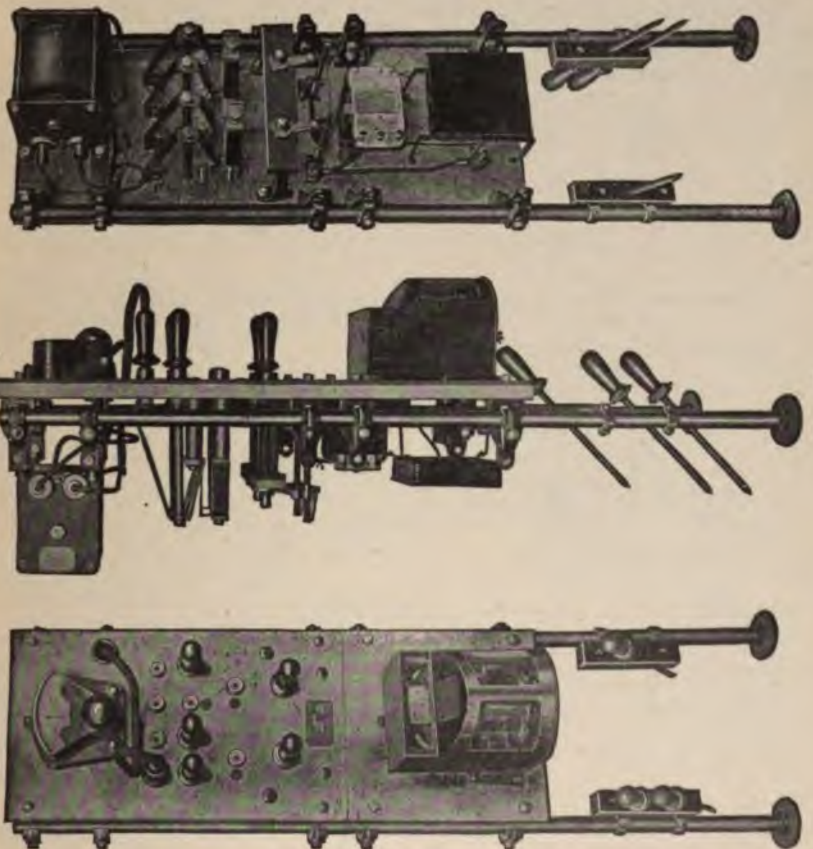


Fig. 27.

the same bedplate. The generator may be shunt or compound wound, as desired. Rotary converters are direct-current generators, though specially designed; they are fitted with collector rings attached to the winding at definite points. The alternating current is fed into these rings and the machine runs as a synchronous

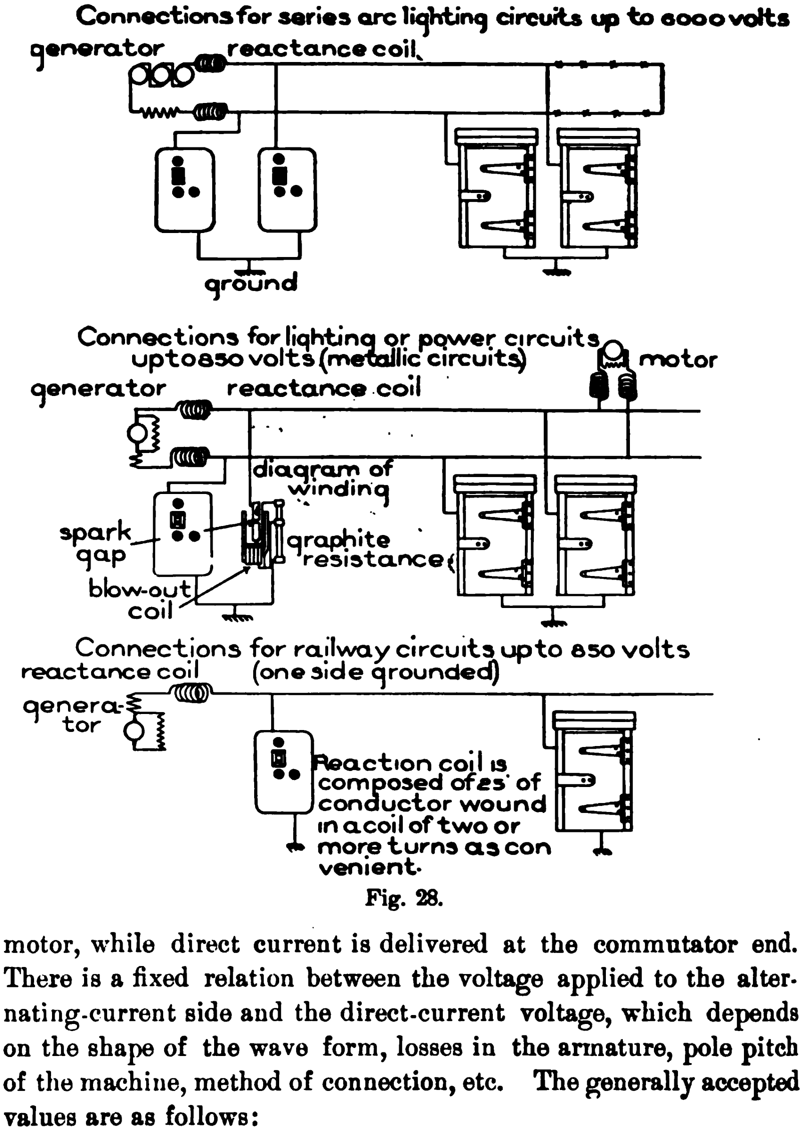

Connections for series arc lighting circuits up to 6000 volts
generator
reactance coil
ground
Connections for lighting or power circuits up to 850 volts (metallic circuits)
motor
generator
reactance coil
diagram of winding
spark gap
graphite resistance
blow-out coil
Connections for railway circuits up to 850 volts (one side grounded)
reactance coil
generator
Reaction coil is composed of 25' of conductor wound in a coil of two or more turns as convenient.

Fig. 28.

motor, while direct current is delivered at the commutator end. There is a fixed relation between the voltage applied to the alternating-current side and the direct-current voltage, which depends on the shape of the wave form, losses in the armature, pole pitch of the machine, method of connection, etc. The generally accepted values are as follows:

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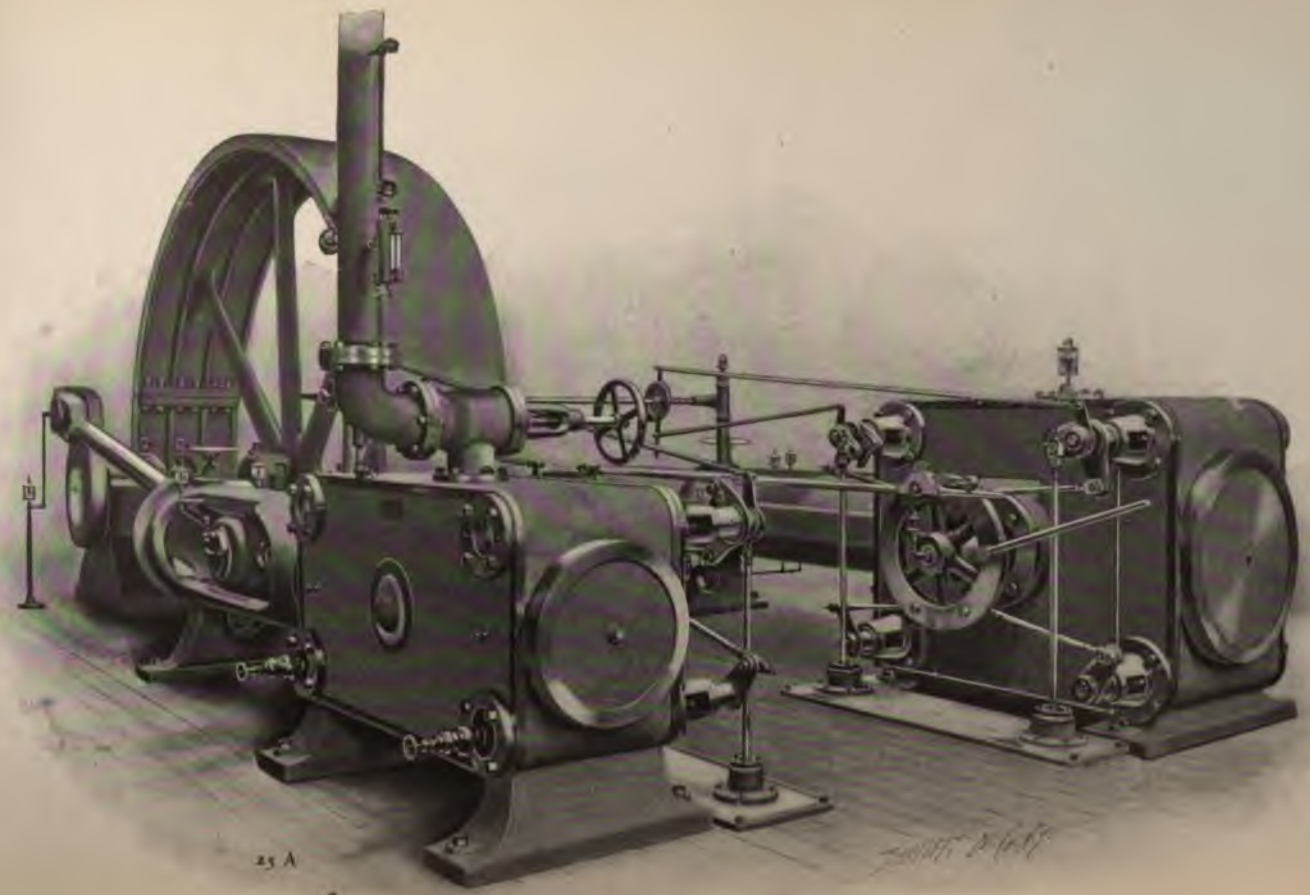


25 A

COMPOUND CORLISS ENGINE.

Frick Company.

TABLE 13.

Full Load Ratios.

Current.		Potential.
Continuous		100
Two-phase and Six-phase (diametrical)	550 volts	72.5
	250 "	73
	125 "	73.5
Three-phase and Six-phase (Y or delta)	550 "	62
	250 "	62
	125 "	63

The increase of capacity of six-phase machines over other machines of the same size is given in Table 14.

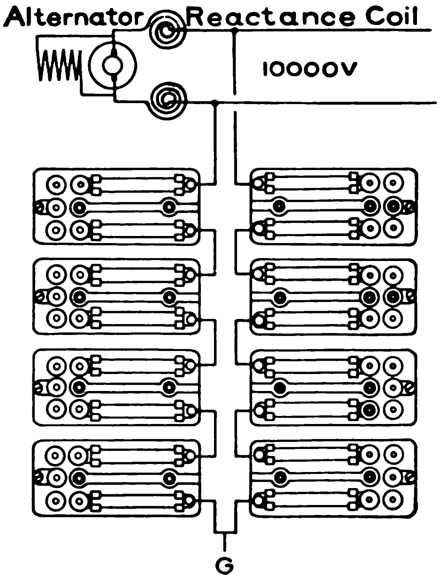


Fig. 29.

This increase is due to the fact that, with a greater number of phases, less of the winding is traversed by the current which passes through the converter. The saving by increasing the number of phases beyond six is but slight and the system becomes too complex. Rotary converters may be over-compounded by the addition of series fields, provided the reactance in the alternating circuits be of a proper value. It is customary to insert reactance coils in the leads from the low-tension side of the step-down transformers to the collector rings to bring the reactance to a value which will insure the desired compounding. Again, the voltage may be controlled by means of induction regu-

TABLE 14.

Capacity Ratios.

Continuous-current generator	100
Single-phase converter	85
Two-phase converter	164
Three-phase converter	134
Six-phase converter	196

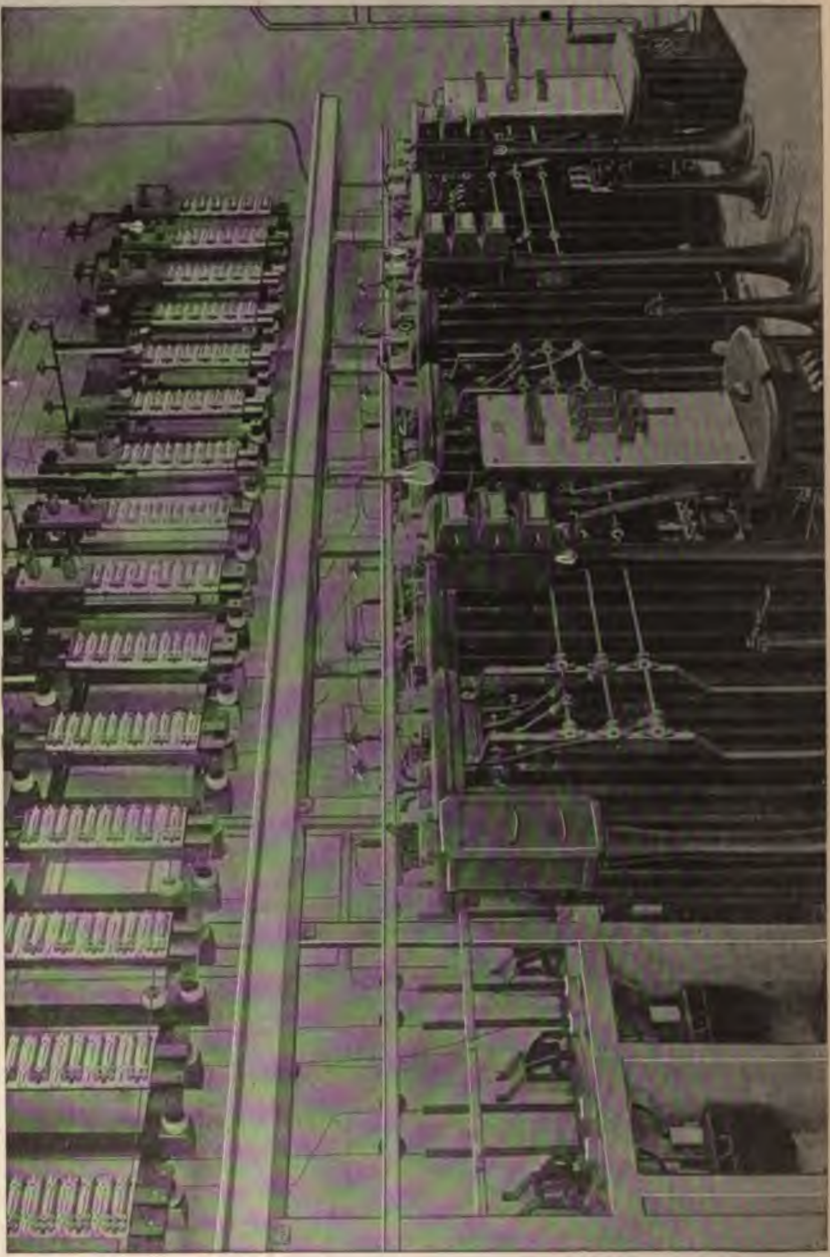


Fig. 30. 26,400-Volt Lightning Arrester Installation.

lators placed in the alternating-current leads. Motor-generators are more costly and occupy more space than rotary converters, but the regulation of the voltage is much better and they are to be preferred for lighting purposes.

Buildings. The power station usually has a building devoted entirely to this work, while the substations, if small, are often made a part of other buildings. While the detail of design and construction of the buildings for power plants belongs primarily to the architect, it is the duty of the electrical engineer to arrange the machinery to the best advantage, and he should always be consulted in regard to the general plans at least, as this may save much time and expense in the way of necessary modifications. The general arrangement of the machinery will be taken up later, but a few points in connection with the construction of the buildings and foundations will be considered here.

Space must be provided for the boiler,—this may be a separate building—engine and dynamo room, general and private offices, store rooms and repair shops. Very careful consideration should be given to each of these departments. The boiler room should be parallel with the engine room, so as to reduce the necessary amount of steam piping to a minimum, and if both rooms are in the same building a brick wall should separate the two, no openings which would allow dirt to come from the boiler room to the engine room being allowed. The height of both boiler and engine rooms should be such as to allow ample headway for lifting machinery and space for placing and repairing boilers, while provision should be made for extending these rooms in at least one direction. Both engine and boiler rooms should be fitted with proper traveling cranes to facilitate the handling of the units. In some cases the engines and dynamos occupy separate rooms, but this is not general practice. Ample light is necessary, especially in the engine rooms. The size of the offices, store rooms, etc., will depend entirely on local conditions.

The foundations for both the walls and the machinery must be of the very best. It is well to excavate the entire space under the engine room to a depth of eight to ten feet so as to form a basement, while in most cases the excavations must be made to a greater depth for the walls. Foundation trenches are sometimes

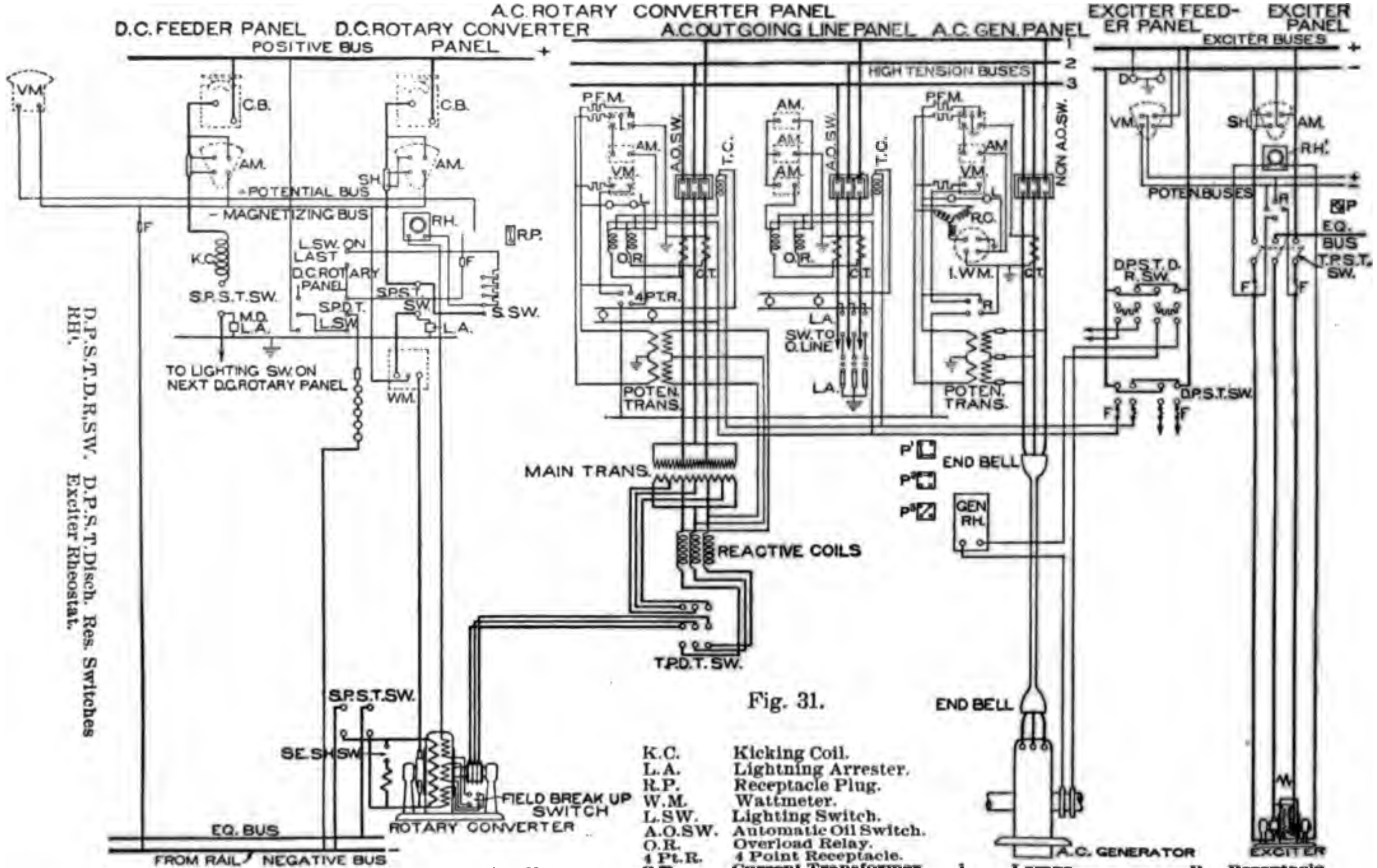


Fig. 31.

K.C.	Kicking Coil.
L.A.	Lightning Arrester.
R.P.	Receptacle Plug.
W.M.	Wattmeter.
L.SW.	Lighting Switch.
A.O.SW.	Automatic Oil Switch.
O.R.	Overload Relay.
4 Pt.R.	4 Point Receptacle.
C.T.	Current Transformer.
T.C.	Tripping Coil.
RH.	Rheostat.
P_1	Plug for Machine Starting.
P_2	Plug for Reading Voltage.
P_3	Plug for Machine Running.
L.	Lamps.
R.C.	Reactive Coils.
R.	Receptacle.
D.	Detector.
D.P.S.T.D.R,SW.	D.P.S.T. Disch. Res. Switches
RH'.	Exciter Rheostat.

filled with concrete to a depth sufficient to form a good underfooting. The area of the foundation footing should be great enough to keep the pressure within a safe limit for the quality of the soil.

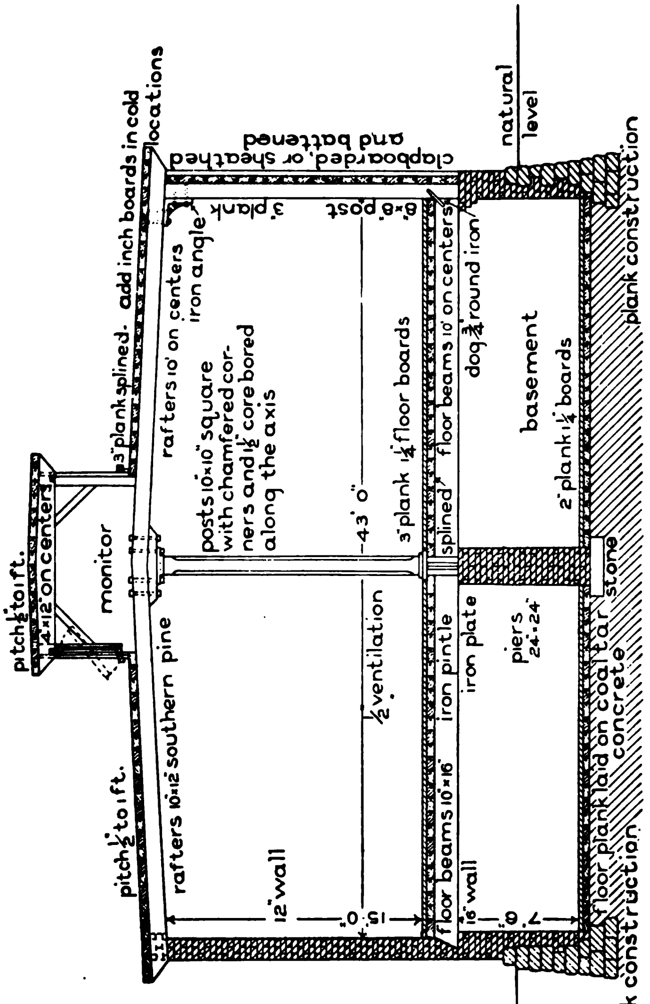


Fig. 32.

The walls themselves may be of wood, brick, stone, or concrete. Wood is used for very small stations only, while brick may be used alone or in conjunction with steel framing, the latter construction being used to a considerable extent. If brick alone is used, the walls should never be less than twelve inches thick, and eighteen to twenty inches is better for large buildings. They must be amply reinforced with pilasters. Stone is used only for the most expensive stations. The interior of the walls is formed of glazed brick, when the expense of such construction is warranted. In fireproof construction, which is always desirable for power stations, the roofs are supported by steel trusses and take a great variety of forms. Fig. 32 shows what has been recommended as standard construction for lighting stations, showing both brick and wood construction. The floors of the engine room should be made of some material which will not form grit or dust. Hard tile, unglazed, set in cement or wood floors, is desirable. Storage battery rooms should be separate from all others and should have their interior lined with some material which will not be affected by the acid fumes. The best of ventilation is desirable for all parts of the station, but is of particular importance in the dynamo room if the machines are being heavily loaded. Substation construction does not differ from that of central stations when a separate building is erected. They should be fireproof if possible.

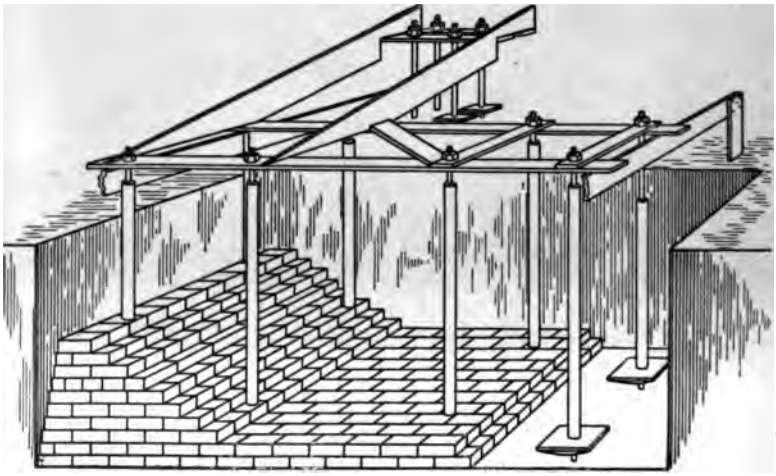
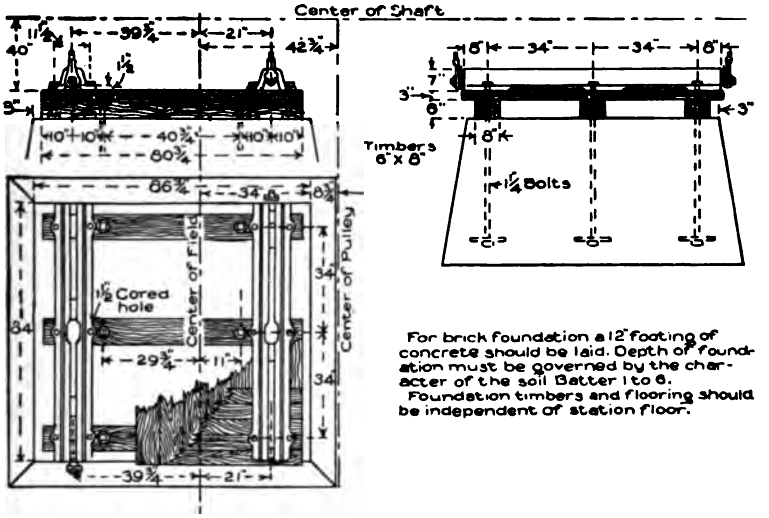


Fig. 33.

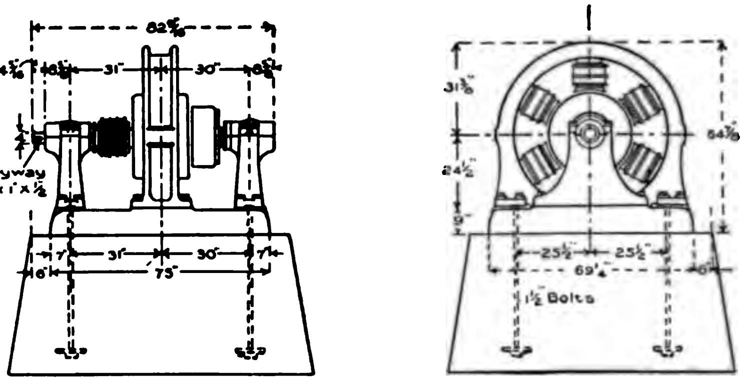
The foundations for machinery should be entirely separate from those of the building. Not only must the foundations be stable, but in some locations it is particularly desirable that no vibrations be transmitted to adjoining rooms and buildings. A loose or sandy soil does not transmit such vibrations readily, but firm earth or rock transmits them almost perfectly. Sand, wool, hair, felt, mineral wool, and asphaltum concrete are some of the materials used to prevent this. The excavation for the foundation is made from two to three feet deeper and two to three feet wider on all sides than the foundation, and the sand, or whatever material is used, occupies this extra space.



For brick foundation a 12" footing of concrete should be laid. Depth of foundation must be governed by the character of the soil Batter 1 to 6.
Foundation timbers and flooring should be independent of station floor.

Fig. 34.

Brick, stone, or concrete is used for building up the greater part of machinery foundations, the machines being held in place by means of bolts fastened in masonry. A template, giving the location of all bolts to be used in holding the machine in place, should be furnished, and the bolts may be run inside of iron pipes with an internal diameter a little greater than the diameter of the bolt. This allows some play to the bolt and is convenient for the final alignment of the machine. Fig. 33 gives an idea of this construction. The brickwork should consist of hard-burned brick of the best quality, and should be laid in cement mortar. It is well to fit brick or concrete foundations with a stone cap, forming a level surface on which to set the machinery, though this is not necessary. Generators are sometimes mounted on wood bases to furnish insulation for the frame. Fig. 34 shows the foundation for a 150 K.W. generator, while Fig. 35 shows the foundation for a rotary converter.



For brick foundation a 12" footing of concrete should be laid Depth of foundation must be governed by the character of the soil. Batter 1 to 6.

Fig. 35.

Station Arrangement. A few points have already been noted in regard to station arrangement, but the importance of the subject demands a little further consideration. Station arrangement depends chiefly upon two facts—the location and the machinery to be installed. Undoubtedly the best arrangement is with all of the machinery on one floor with, perhaps, the operating switchboard mounted on a gallery so that the attendants may have a clear view of all the machines. Fig. 36 shows the simplest arrangement of a plant using belted machines. Fig. 37 shows an arrangement of units where a jack shaft is used. Direct-current machines should be placed so that the brushes and commutators are easily accessible and the switchboard should be placed so as to not be liable to accidents, such as the breaking of a belt or a fly-wheel.

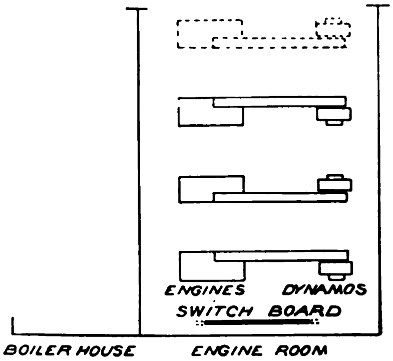


Fig. 36.

When the cost of real estate prohibits the placing of all of the machinery on one floor, the arrangements shown in Fig. 38 may be used when the machines are belted. It is always desirable to have the engines on the main floor, as they cause considerable vibration when not mounted on the best of foundations. The boilers, while heavy, do not cause such vibration and they may be placed on the second or third floor. Belts should not be run vertically, as they must be stretched too tightly to prevent slipping.

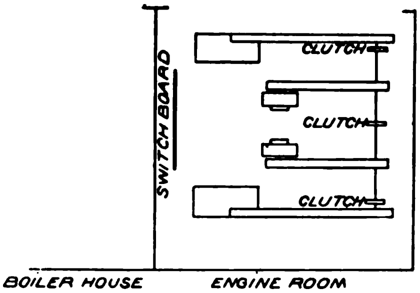


Fig. 37.

Fig. 39 shows a large station using direct-connected units, while Fig. 40 shows the arrangement of the turbine plant of the Boston Edison Electric Illuminating Company. This station will contain twelve such 5,000 K.W. units when completed. Note the arrangement of boilers when several units are required for a single prime mover. The use of a separate room or building for the cables, switches, and operating boards is becoming quite common for high-tension generating plants. The remarkable saving in floor space brought about by the turbine is readily seen from Fig. 41. The total floor space occupied by the new Boston station is 2.64 square feet per K.W. This includes boilers—of which there are eight, each 512 H.P. for each unit—turbines, generators, switches, and all auxiliary apparatus.

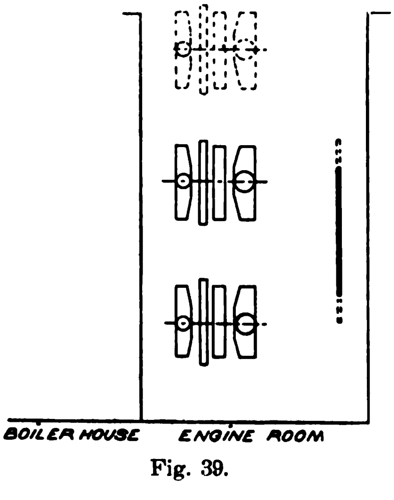


Fig. 39.

When transformers are used for raising the voltage, they may be placed in a separate building, as is the case at Niagara Falls, or the transformers may be located in some part of the dynamo room preferably in a line parallel to the generators.

Fig. 42 shows the arrangement of units in an hydraulic plant. Fig. 43 is a good example of the practice in substation arrangement. Here the switchboard is mounted at one end of the room, while the rotary converters and transformers are arranged along either side of the building.

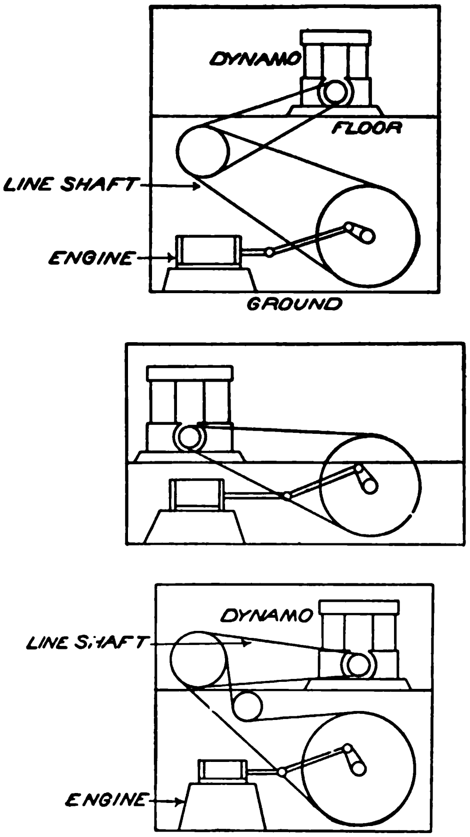


Fig. 38.

Large cable vaults are installed at the stations operating on underground systems, the separate ducts being spread out, and sheet-iron partitions erected to prevent damage being done to cables which were not originally defective, by a short circuit in any one feeder.

Station Records. In order to accurately determine the cost of generating power and to check up on uneconomical or improper methods of operation and lead to their improvement, accurately kept station records are of the utmost importance. Such records should consist of switchboard records, engine-room records, boiler-room records, and distributing-system records. Such records accurately kept and properly plotted in the form of curves, serve admirably for the comparison of station operations from day to day and for the same periods for different years. It pays to keep these records even when additional clerical force must be employed.

Switchboard records consist, in alternating stations, of daily readings of feeder, recording wattmeters, and total recording wattmeter, together with voltmeter and ammeter readings at intervals of about 15 minutes in some cases to check upon the average power factor and determine the general form of the load curve. For direct-current lighting systems volt and ampere readings serve to give the true output of the stations, and curves are readily plotted from these readings. The voltage should be recorded for the bus bars as well as for the centers of distribution.

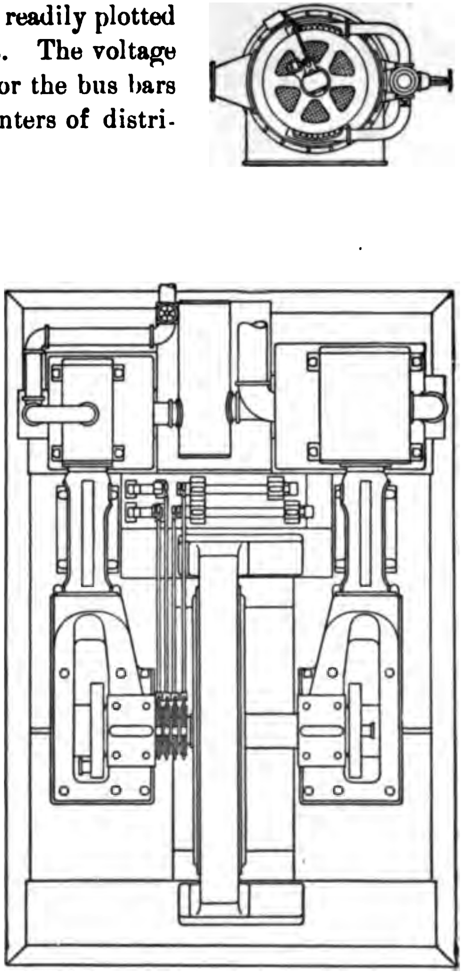


Fig. 41. Comparison of 1500 KW. Corliss Engine and 1500 KW. Curtis Turbine.

Indicator diagrams should be taken from the engines at frequent intervals for the purpose of determining the operation of the valves. Engine-room records include labor, use of waste oil and supplies, as well as all repairs made on engines, dynamos and auxiliaries.

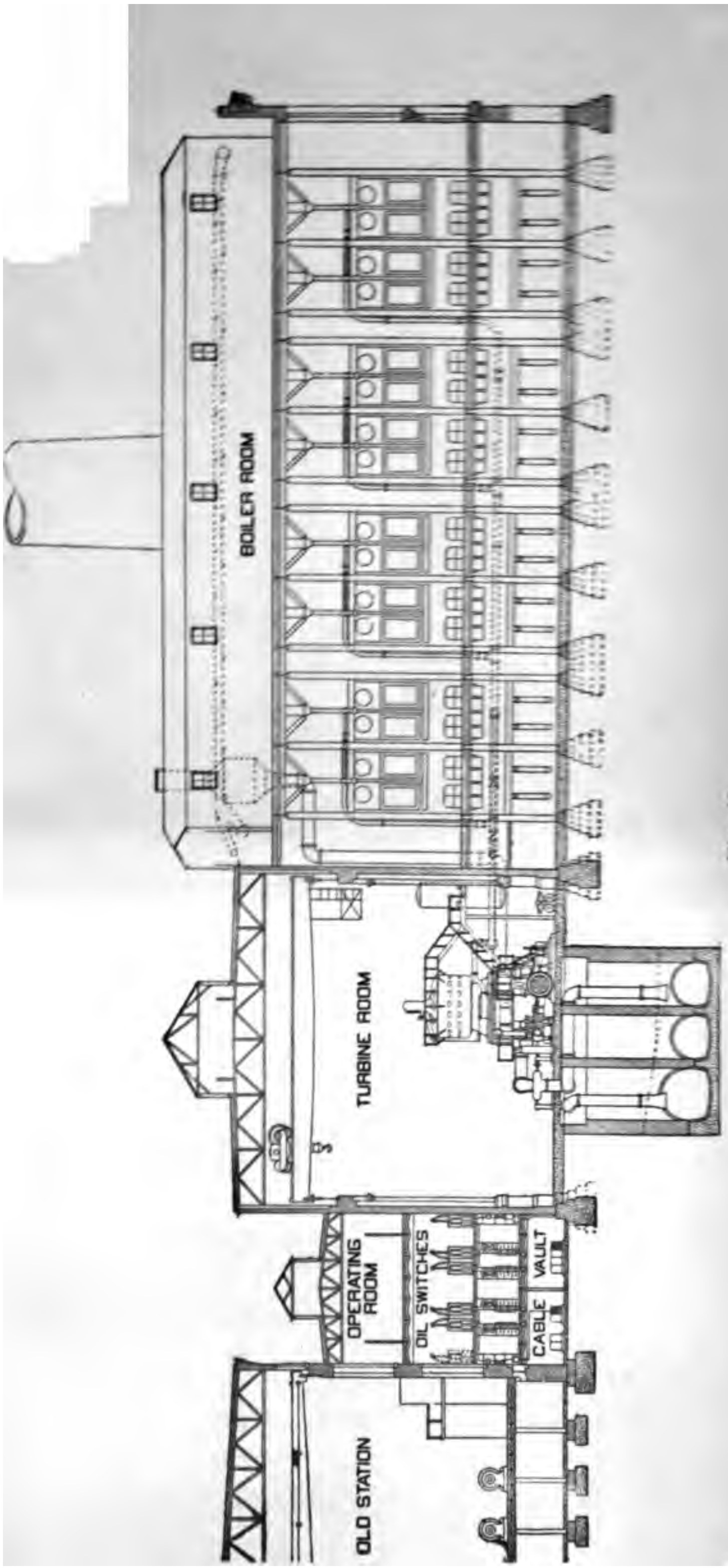

OLD STATION
OPERATING ROOM
OIL SWITCHES
CABLE
VAULT
TURBINE ROOM
BOILER ROOM

Fig. 40.

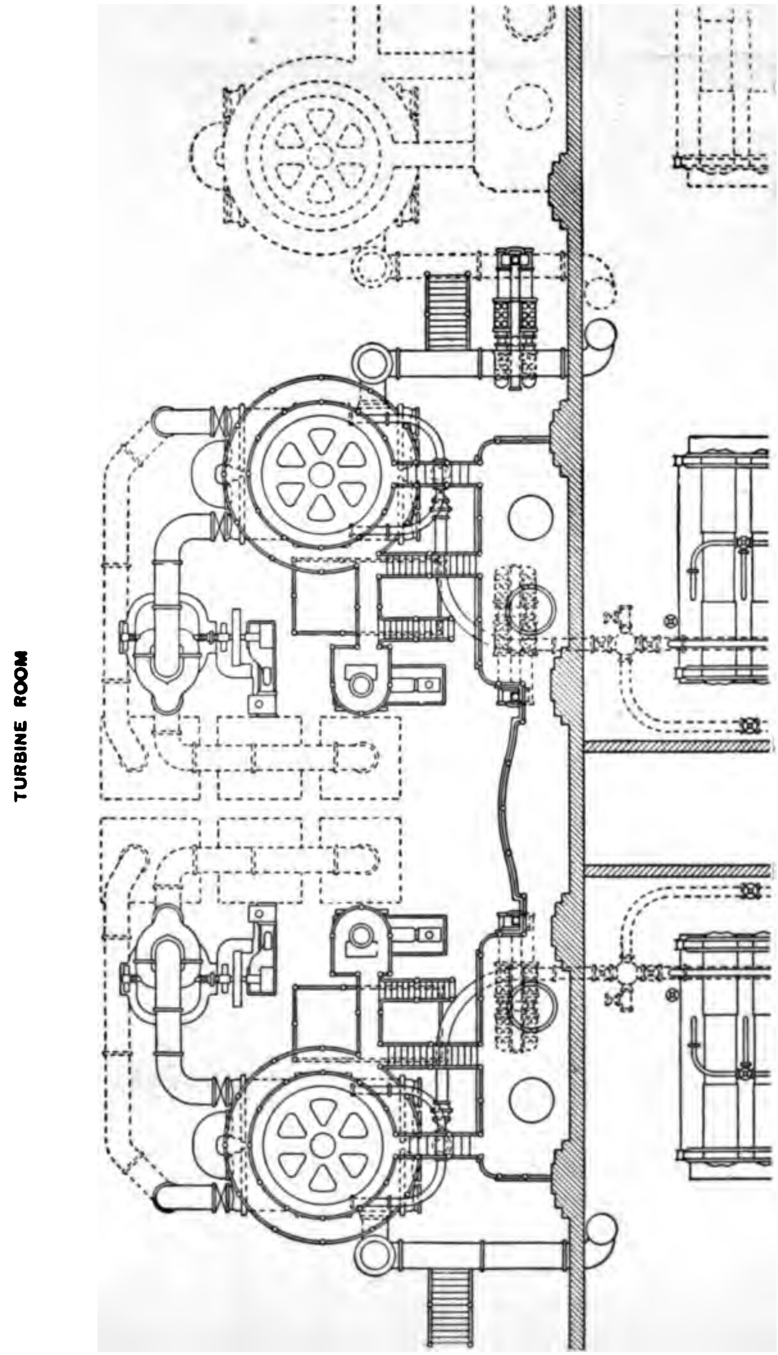


Fig. 40.

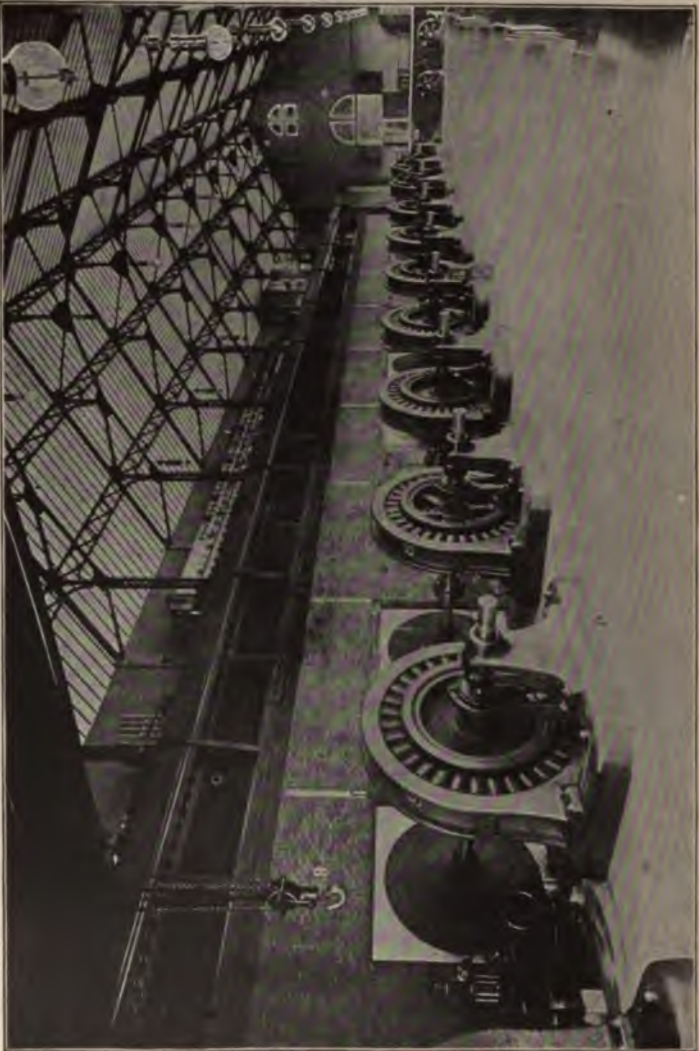


Fig. 42.

Boiler-room records include labor and repairs, amount of coal used, which amount may be kept in detail if desirable, amount of water used, together with steam-gauge record and periodical analysis of flue gases as a check on the methods of firing.

Records for the distributing system include labor and material used for the lines and substations. For multiple-wire systems, frequent readings of the current in the different feeders will serve as a check on the balance of the load.

The cost of generating power varies greatly with the rate at which it is produced as well as upon local conditions. Station operating expenses include cost of fuel, water, waste, oil, etc., cost of repairs, labor, and superintendence. Fixed charges include, insurance, taxes, interest on investment, depreciation, and general office expenses. Total expenses divided by total kilowatt hours gives the cost of generation of a kilowatt hour. The cost of distributing a kilowatt hour may be determined in a similar manner. The rate of depreciation of apparatus differs greatly with different machines, but the following figures may be taken as average values, these figures representing percentage of first cost to be charged up each year:

Fireproof buildings from 2 to 3 per cent.
Frame buildings from 5 to 8 per cent.
Dynamos from 2 to 4 per cent
Prime movers from 2½ to 5 per cent.
Boilers from 4 to 5 per cent.
Overhead lines, best constructed, 5 to 10 per cent.
More poorly constructed lines 20 to 30 per cent.
Badly constructed lines 40 to 60 per cent.
Underground conduits 2 per cent.
Lead covered cables 2 per cent.

Methods of Charging for Power. There are four methods used for charging consumers for electrical energy, namely, the flat-rate or contract system, the meter system, the two-rate meter system, and a system by which each customer pays a fixed amount depending on the maximum demand and in addition pays at a reasonable rate for the power actually used. In the flat-rate system, each customer pays a certain amount a year for service, this amount being based on the estimated amount of power to be used. These rates vary, depending on the hours of the day during which the power is to be used, being greatest if the energy is to be used during peak hours. It is an unsatisfactory method for lighting service, as many customers are liable to take advantage of the company, burning more lights than contracted for and at different hours, while the honest customer must pay a higher rate than is reasonable in order to make the station operation profitable.

This method serves much better when the power is used for driving motors, and is used largely for this class of service.

The simple meter method of charging serves the purpose better for lighting, but the rate here is the same no matter what hour of the day the current is used. Obviously, since machinery is installed to carry the peak of the load, any power used at this time tends to increase the capital outlay from the plant, and users should be required to pay more for the power at such times.

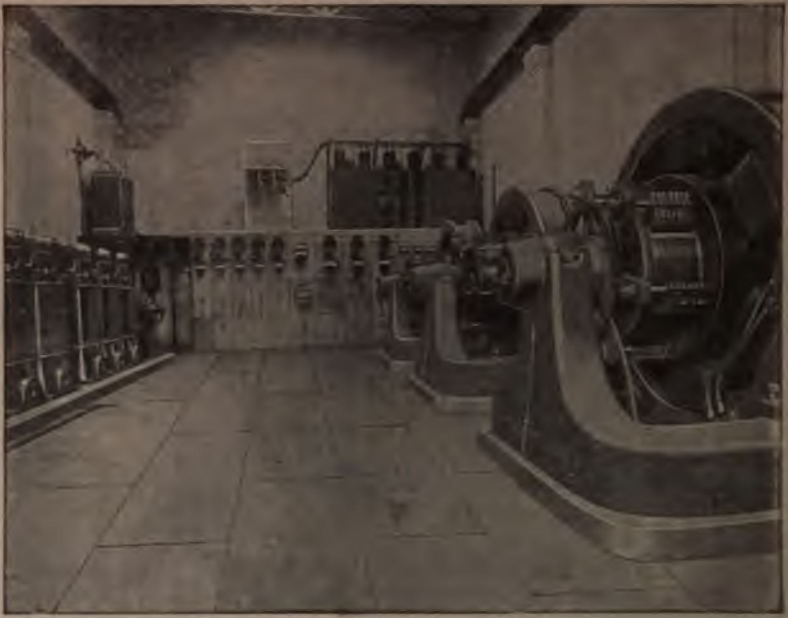


Fig. 43.

The two-meter rate accomplishes this purpose to a certain extent. The meters are arranged so that they record at two rates, the higher rate being used during the hours of heavy load.

There are several methods of carrying out the fourth scheme. In the Brighton System, a fixed charge is made each month, depending on the maximum demand for power during the previous month, a regular schedule of such charges being made out, based on the cost of the plant. An integrating wattmeter is used to record the energy consumed, while a so-called "demand meter" records the maximum rate of demand.

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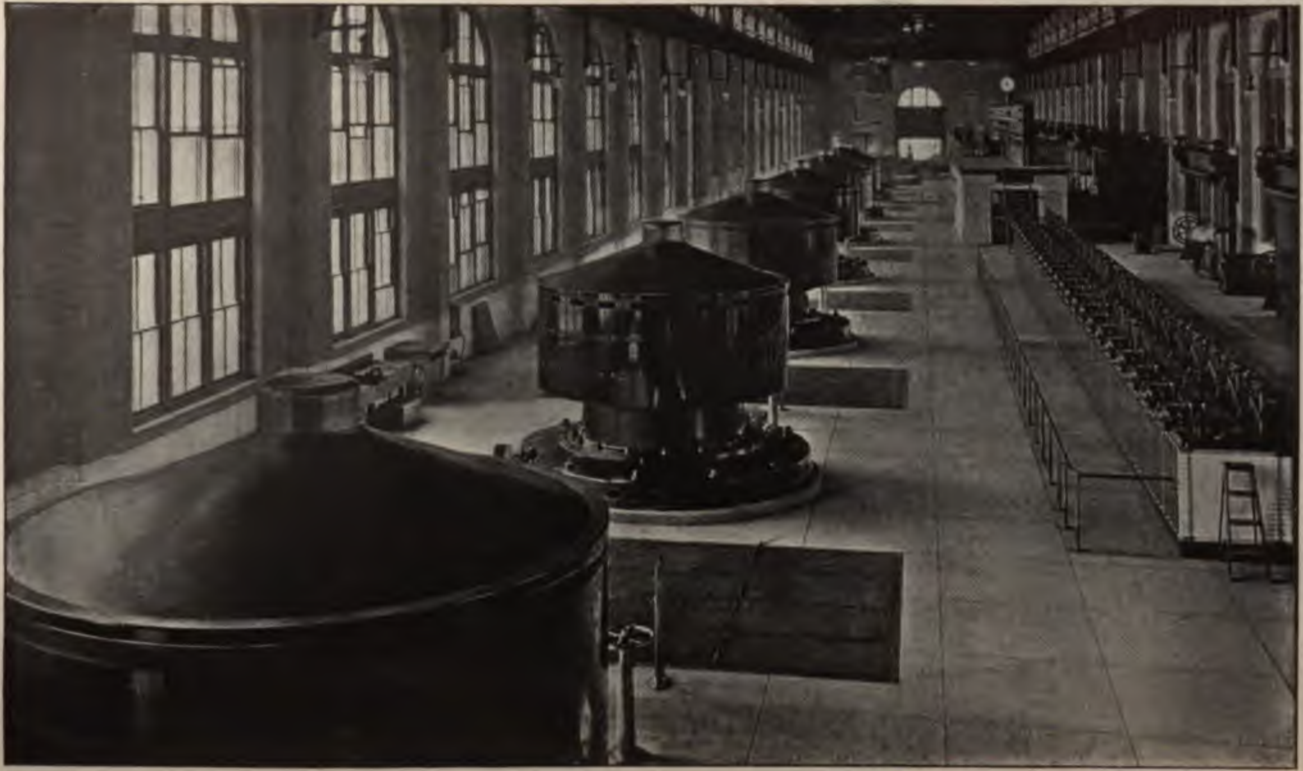


POWER HOUSE NO. 2, NIAGARA FALLS POWER CO.

Eleven Generators of 5,000 H.P. Each.

A QUARTER CENTURY OF AMERICAN CENTRAL STATION ENGINEERING.

Perhaps few of the younger generation engaged in the various branches of electrical work realize that the central-station industry, so large and permanent an institution of our present civic life, is barely a quarter of a century old. Marvelous, indeed, has been the progress of this industry, and its wheels of invention and development are stilling whirling rapidly on. No engineer who values his reputation would venture to prophesy what the next quarter-century will bring us.

Twenty-five years ago the commercial electric lamp was unknown. To-day there are in service in the United States alone nearly twenty million incandescent lamps, to say nothing of the tens of thousands of arc lamps and the few hundred thousand horse-power in electric motors. To-day nearly every city of any importance in America has an electric plant furnishing light and power to its citizens. Magnificent stations have sprung up in our large cities, representing millions of dollars in investment; and electricity is being distributed to nearly every corner of those cities. It may be of interest, then, to look back over the history of this industry, and see some of the steps by which it reached its present splendid growth.

In all the world's history of industrial progress, perhaps no chapter is more full of scientific and heroic romance than that dealing with the birth of the electric-light industry. To the youth of to-day no story could give greater inspiration than that of the men who were the leading figures—the great minds and the energetic workers—during the early days of central-station development. These men contributed as much toward the nation's growth as did our warriors and our statesmen. Most of them are still with us, and are still active in solving engineering problems. It was the good fortune of the readers of the *Electrical World and Engineer* to see, in its recent thirtieth anniversary issue, some interesting reminiscences of these early workers, and thus have brought home to them the youthful age of the industry is not the purpose of this paper, however, to relate biography, but rather to treat of the more prosaic subject of the growth of the central station from its small beginnings to the magnificent proportions of to-day.

BRUSH ARC SYSTEM.

In 1879, there was erected in Cleveland, Ohio, a series-arc system designed by Charles F. Brush. The dynamo furnishing current for these lamps had been built by Brush during the preceding year. The electric arc itself had been discovered by Sir Humphry Davy in London about the year 1802, the source of current for his lamp being a battery of several thousand cells. As the dynamo had not at that time come into existence, the commercial importance of the discovery was not then apparent.

From this first system of Brush's, dates the history of commercial electric lighting in America. As stated, the lamps of this system were all connected in series, so that the same current passed through all of them. With many lamps on the circuit this required a fairly high voltage. The efforts of many investigators were then directed toward developing an incandescent lamp for these circuits so that the lights could be used indoors where the arc lamps would be too brilliant. In order to obtain a lamp requiring only a low voltage, which is a desirable feature in series connection, a lamp of low resistance is necessary.

EDISON CONSTANT-POTENTIAL SYSTEM.

The master mind of Thomas Edison soon saw that a series system with high voltage on each line would never become commercially successful for general house lighting; therefore he set about to design a system which should properly meet the required conditions. On February 5, 1880, he patented a constant-potential system consisting of feeders and mains, with the load connected in parallel, or multiple arc, between the two wires forming the positive and the negative conductors, as shown in Fig. 1. How well this succeeded is evidenced by the present almost universal use of this system of connection. Obviously, a low-resistance lamp would not do on a constant-potential circuit; Edison, therefore, first developed a high-resistance lamp. His success in this is well known. His patent for the lamp is dated November 4, 1879. In December of that year he had a number of these lamps on exhibition at his laboratory in Menlo Park, and the following year he equipped his house and grounds with the lamps. The newspapers of the time were filled with accounts of what the "Wizard of Menlo Park" had accomplished, and visitors flocked to the town in great numbers to see the lights.

The first Edison plant for the public supply of current was located at Appleton, Wisconsin, where in 1881, was installed one of the first of the lanky bipolar dynamos, connected by a belt to a water wheel in a little wooden shed. The first central station for general distribution of current to incandescent lamps was started January 12, 1882, at Holborn Viaduct in London, England. The second and the third Jumbo dynamos (so named because of their bulk), built by Edison in America, furnished the current for this system. They weighed twenty-three tons each, and had a combined capacity of 3,000 lights. The first of these machines built by Edison was sent to the Paris Exposition of 1881. By October, 1882, the Edison Manufacturing Company had installed in all 123 plants, with a total of about 22,000 lamps.

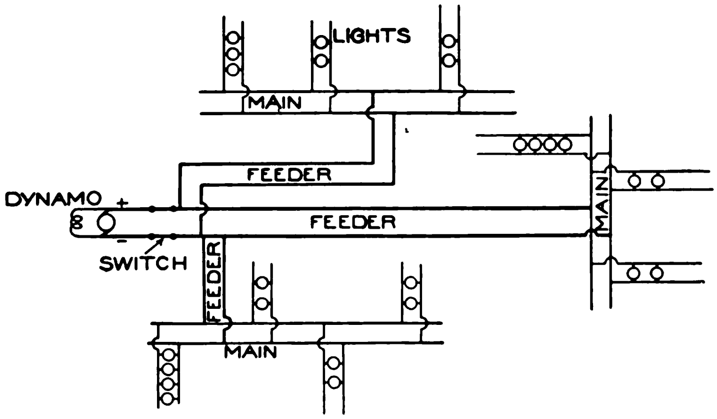


Fig. 1.

The Edison Tube. During this time Edison's attention had been directed toward laying out a system for the city of New York. In such a city it was desirable to have the system underground. Accordingly, the Edison tube was designed. This consisted two half-round copper bars laid in iron pipe in lengths of about twenty feet, and insulated by means of a tar compound While there are still many miles of these tubes giving good service, all new underground work has for some years been done with lead-covered cables drawn into ducts laid in the streets, the connections being made in manholes. Fig. 2 shows a duct system made of cement-lined iron pipe laid in a bed of concrete.

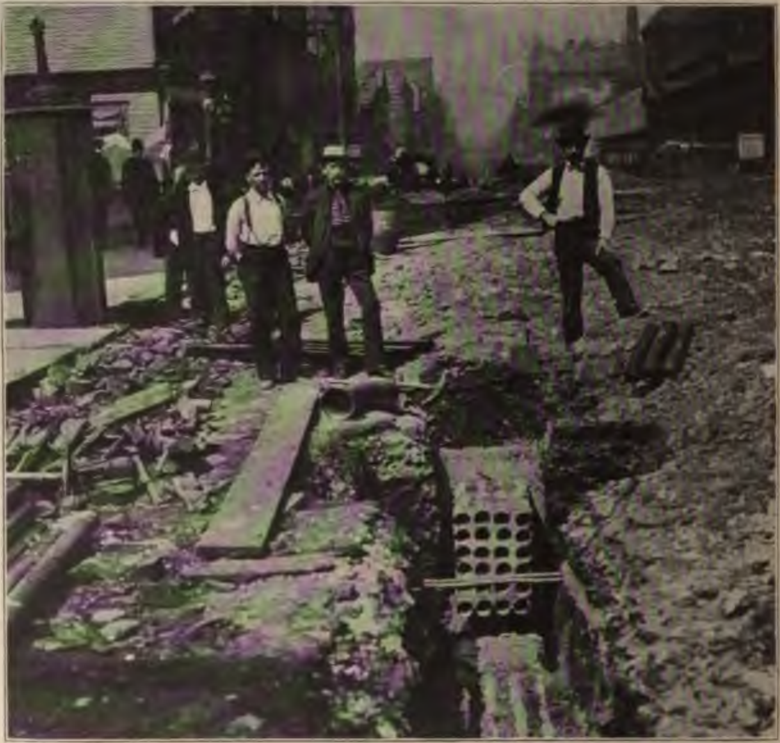


Fig. 2.

Three-Wire Direct-Current System. Late in 1882, Edison made a series of experiments with a view toward a more economical distribution system, and he then devised the well-known three-wire system, in which two generators are connected in series, and a conductor is connected to their junction, and run out into the system as the neutral wire. This is illustrated in Fig. 3. By connecting the lights so that the load on the two sides of the system is nearly balanced, a saving of about sixty per cent was effected in the amount of copper necessary to transmit the same energy. This is due to the fact that, in the three-wire system, the current is transmitted at 220 volts instead of at 110, thus requiring for the same number of watts only half as many amperes; and therefore a smaller wire can be used. If the load on the two sides of the system is not balanced, the difference between the current in the positive conductor and that in the negative will come back to the dynamos over the neutral wire. Dr. John Hopkinson, in England, and Werner von Siemens, in Germany, devised similar systems at about the same time.

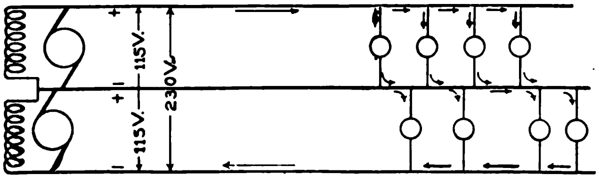


Fig. 3.

It was not until 1884 that electric motors were first used in New York; and the arc lamp designed for parallel connection on the constant-potential circuit was not introduced until 1889. The success of the constant-potential arc lamps made it possible for central stations to do all classes of business with one system of distribution—which was an important step in the march of progress. In 1890 the Duane Street Station was built in the heart of the Edison system, with a total engine capacity of 11,800 H.P. in direct-connected units.

In Boston, the Edison Electric Illuminating Company was organized in December, 1885, and the first station was started in February of the next year, using the Edison three-wire system of distribution. In 1887, a second station was built to take care of the load in another section of the city. Here, for the first time, was adopted the method of using 220-volt motors on the Edison system, connecting them to the two outer mains instead of between one outer and the neutral (110 volts), as had heretofore been done.

The Edison Companies. The good financial showing made by this company led to the formation of Edison Companies in many other cities, among the largest of which were Chicago and Philadelphia; and to the building of two up-town stations in New York. The original plant of the Western Edison Electric Light Company (now the Chicago Edison Company), a view of the dynamo room of which is shown in Fig. 4, was built at 139 Adams Street in 1887, and contained at first eight 100-K.W. Edison bipolar dynamos belted to four 250-H.P. engines located on the floor below. In 1891, additional dynamos and engines were added, until the total capacity reached 3,400 K.W.

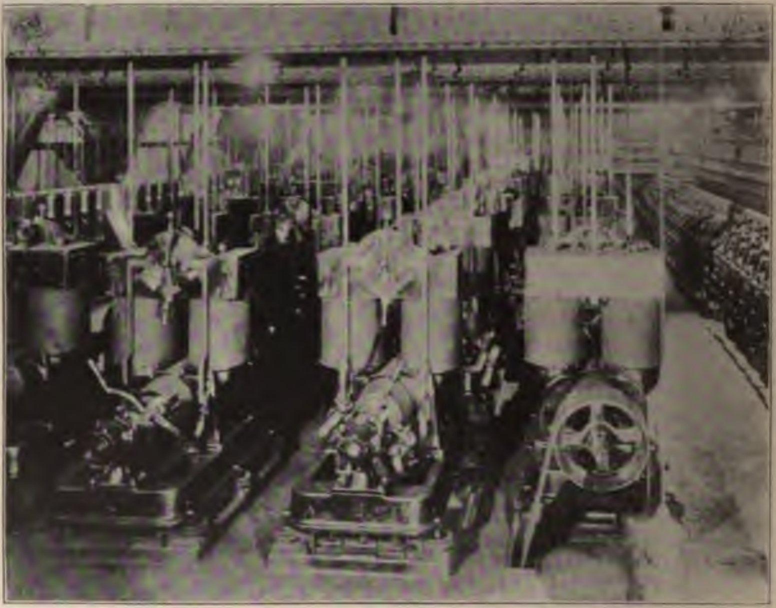


Fig. 4. Dynamo Room, Old Adams St. Station, Chicago Edison Co.

In the summer of 1892, the big station at Harrison Street, representing the most modern central-station engineering of the time, was started; and the next year the Adams Street Station was dismantled. The center of distribution, however, was kept at Adams Street, the current generated at the new station, about 3,000 feet away, being sent to this center over a trunk line consisting of twenty-eight Edison tubes and cables with a total sectional area of 66,000,000 circular mils. Of this, 9,000,000 c.m. of section was used for the neutral conductors, leaving 28,500,000 c.m. for each of the outsides, that is, for the positive and the negative.

In its onward march the Chicago Edison Company absorbed a number of plants, chief of which was that of the Chicago Arc Light & Power Company, located at Washington Street and the river. The systems operated from this station at that time consisted of series arcs, 500-volt direct current for power, and some 133-cycle 1,000-volt alternating-current lines. In 1894, there were added the Wabash Avenue Station near 27th Street on the South Side, with an Edison three-wire system and some series-arc lines; and the North Side Station at Clark and Oak Streets, which consisted solely of Edison generators connected to the usual three-wire system (Fig. 5). Fig. 6 is a view of the switchboard at Harrison Street Station. Fig. 6*a* is a back view of the generator gallery of this board, and shows the heavy copper bus bars. Fig. 7 is a cross-section of the engine and boiler rooms at Harrison Street Station, and Fig. 8 shows one of the 1,200-H.P. Southwark engines direct-connected to two 115-volt 400-K.W. generators. One of these dynamos connects with the positive, and the other with the negative, of the three-wire system.

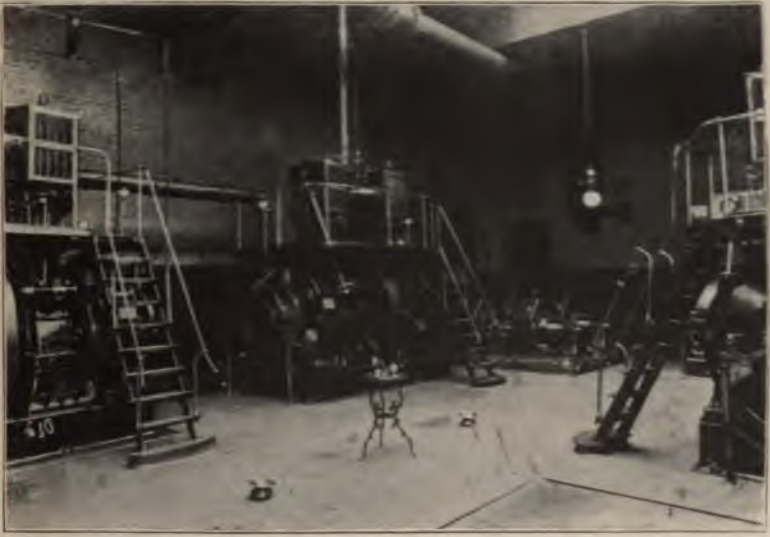


Fig 5. North Side Station, Chicago Edison Co.

Conservative Brooklyn waited to see what success was met by electric-light companies in other cities before its capitalists em-

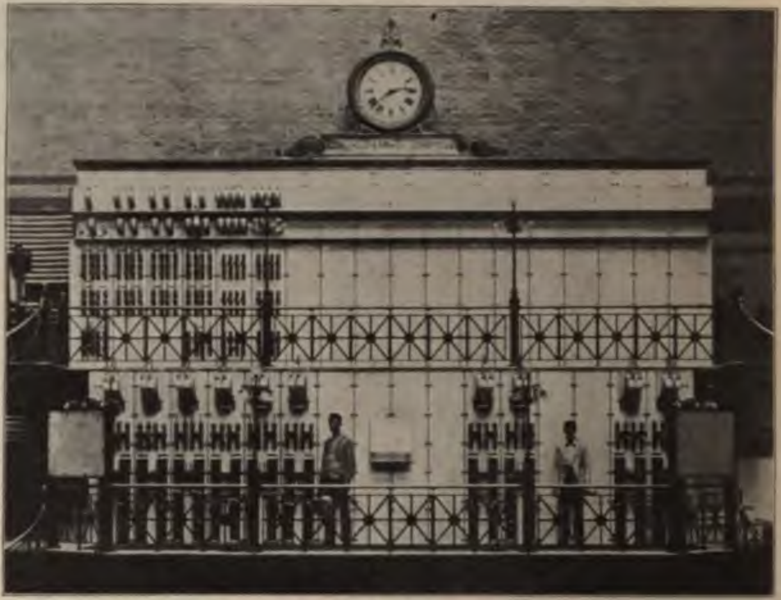


Fig. 6. Switchboard at Harrison Street Station.

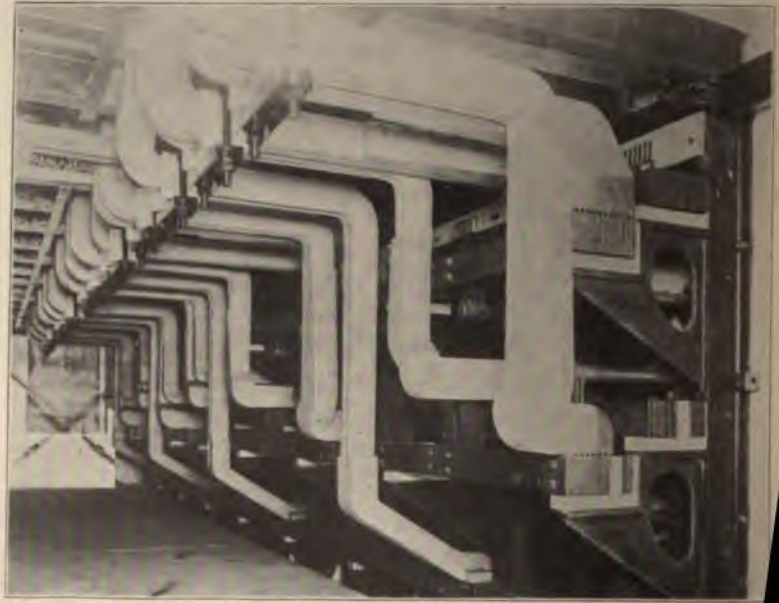


Fig. 6a. Back of Generator Gallery, Harrison Street Station.

barked on such enterprises, but in 1889 that city was added to the list of those having a central station for the production of electricity. In that year the Edison Electric Illuminating Company of Brooklyn built its first station on Pearl Street, and started operations with a load of 6,600 incandescent lamps connected to the system. The dynamos used were four of the Edison bipolar type of 100-K.W. capacity, each two of which were belted to a 250-H.P. cross-compound engine and were connected to an underground three-wire distribution system. In 1893, the station was remodeled, and larger dynamos were introduced direct-connected to vertical cross-compound condensing engines.

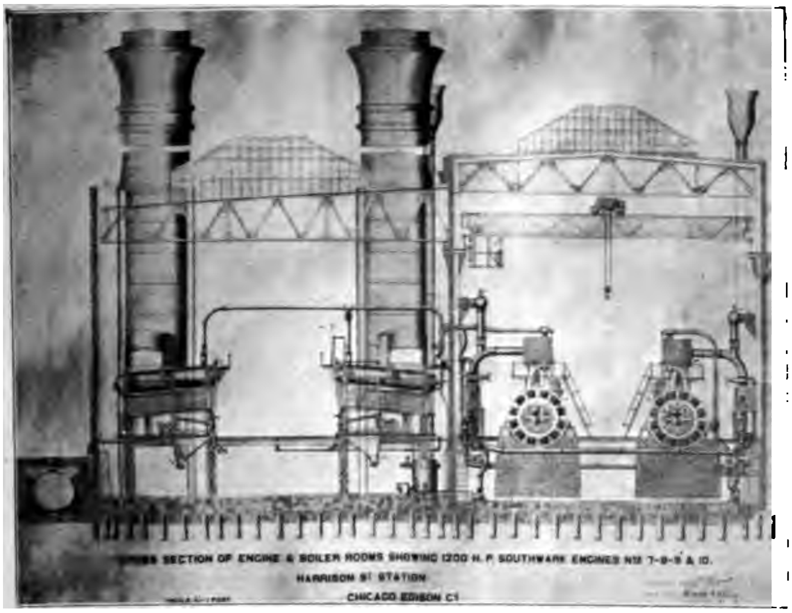
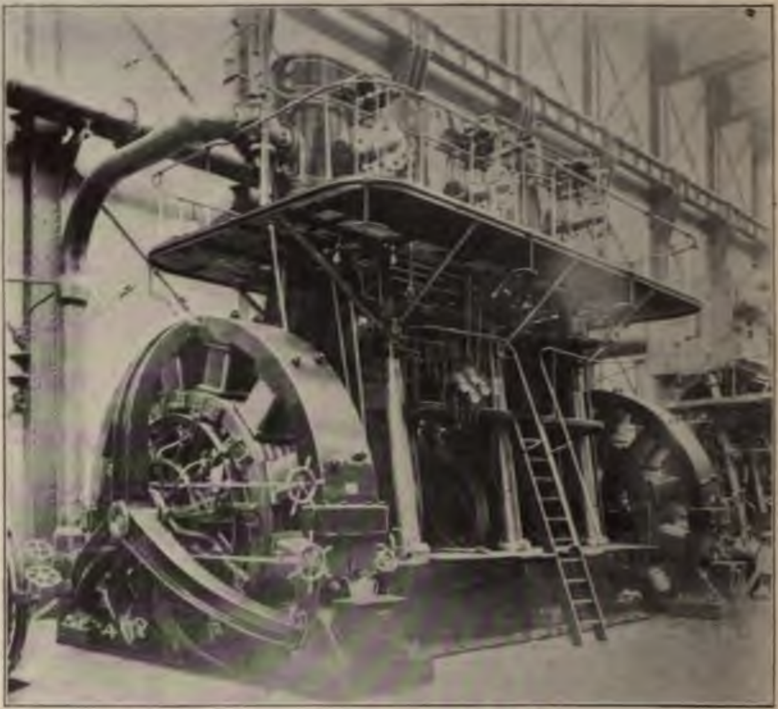

CROSS SECTION OF ENGINE & BOILER ROOMS SHOWING 1200 H.P. SOUTHWARK ENGINES NOS 7-8-9 & 10.
HARRISON ST STATION
CHICAGO EDISON CO

Fig. 7. Cross-Section of Engine and Boiler Rooms, Harrison Street Station

ALTERNATING-CURRENT SYSTEMS.

The development of the alternating-current system in America is due largely to Mr. George Westinghouse, who, in 1885, had built at Pittsburg, Pa., an experimental plant to work out the system devised by Gaulard and Gibbs in England. The first commercial result of the Westinghouse investigations, carried on



Fig, 8. 1200 H.P. Southwark Engine and 400 K.W. Generator.

by Shallenberger, Stanley, and others, appeared in the plant installed at Buffalo, N. Y., in November, 1886. The following year, 65 plants, with a total capacity of 125,000 lights, were built, and the increase thereafter was rapid.

With a direct-current three-wire system using 230 volts between outside conductors, it is uneconomical to transmit current much farther than one and a half miles, because of the prohibitively large amount of copper necessary to keep down the loss in the feeders. The resistance of a conductor varies with the length; and as it requires the expenditure of energy to send a current over a resistance, obviously a high resistance means a large amount of energy lost in the transmission. By increasing the cross-section of the feeder, this resistance can be kept low; but the cost of the feeder would then be prohibitive. By means of the alternating-current system with static transformers, connected as shown in Fig. 9, energy can be transmitted at a much higher voltage from the station. The higher the voltage of transmission, the smaller will be the current (amperes) for a given energy (watts); therefore with the high-voltage system, a given energy can be transmitted over a much smaller wire than would be required for that same energy at a low voltage. In the transformers placed at or near the point where the current is to be used, the pressure is "stepped down" to the voltage of the lamps on the circuit.

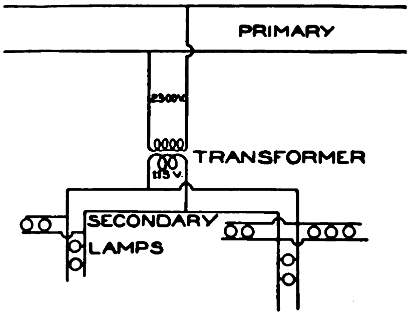


Fig. 9.

The regulation—that is, the steadiness and constancy—of the voltage of these alternating-current lines, was very much poorer than that of the direct-current system. This was largely due to the effects of self-induction, which is ever present with alternating currents. The early incandescent lamp used on the direct-current 110-volt systems was rather delicate, and had only a short life when burned on a circuit in which the pressure fluctuated very much. Consequently, it could not be used economically on the existing alternating-current lines. A 50-volt lamp could be made far more stable, and, largely because of this, the secondaries of the early transformers were wound for 50 volts. The primaries were wound for use on 1,000-volt circuits—which was then considered as high as desirable, because of the difficulties of insulating the line, the transformers, and other apparatus on which this voltage was applied. Rapid advance, however, was made in the art of insulating, and soon this primary pressure was doubled. Most of the city A. C. distributing systems now have a primary pressure of about 2,300 volts. It is interesting to note that the insulators used on the early European high-tension lines were constructed with a trough along the edge on the inner side, which was filled with oil in order to prevent current leaking over the surface of the insulator to the pin and thus to ground, by way of the cross-arm and pole, on wet days.

One of the larger of the early stations for the generation and distribution of alternating current was built in St. Louis, Mo., in 1889. The system adopted was single-phase, 1,200 volts, 60 cycles*, with a three-wire Edison system for the secondaries. These secondaries were tied together at street crossings, forming a complete network similar to that described for the direct-current system, and shown in Fig. 10. In this case the feeders of the D. C. system were replaced by the high-tension A. C. feeders and transformers, the latter being treated as part of the feeders. Pressure wires were connected to the secondaries of the transformers, and were run back to the station voltmeters to be used by the switchboard operator in regulating.

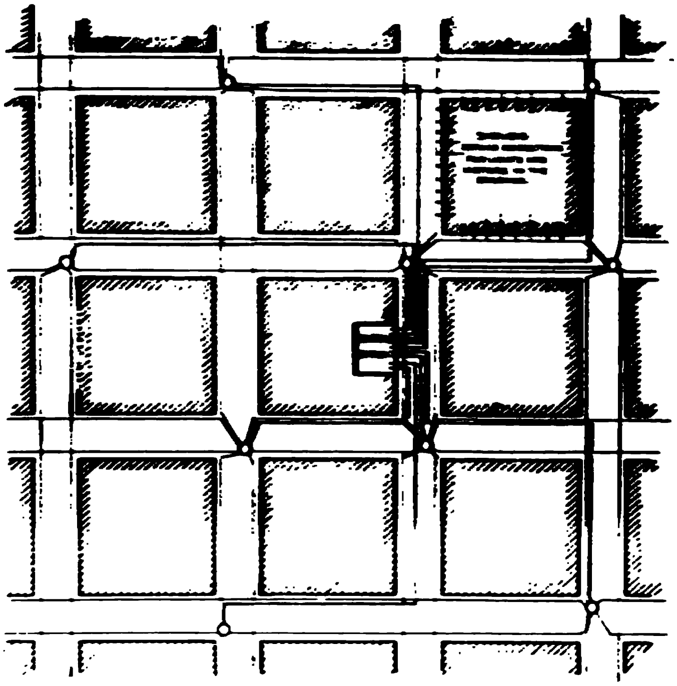


Fig. 10.

An interesting alternating-current line was built between San Bernardino and Pomona, California, in 1891. Here a transmission pressure of 10,000 volts was used, obtained by means of connecting the 500-volt primaries of twenty transformers in series. Thus each transformer had to have insulation for a working pressure of only 500 volts, which was comparatively easy to produce.

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*Note. A current which alternates 120 times per second has 60 double alternations or "cycles" per second.

In 1891, the celebrated three-phase transmission line from Lauffen to Frankfort, in Germany, was operated. Originally this was intended for transmitting energy generated by water power at Lauffen, to the city of Heilbron, six miles away; but it was first used in the now famous transmission to Frankfort, a distance of 110 miles, at the time of the Frankfort Exhibition. The dynamo, built at the Oerlikon Works in Switzerland, was star-connected, and generated a star pressure of about 50 volts.

In a three-phase star-connected generator, the armature windings consist of three branches which are connected at one end to a common point. These branches are so placed on the armature core that the wave of the alternating pressure is set up in one coil a little later than is the wave of pressure set up in the coil immediately ahead of it, and a little sooner than the wave in the coil immediately back of it. These three pressures then follow each other in regular succession, the phase difference (the time between similar values of the different waves) being equal to one-third period.* The wires leading to the other ends of the three armature coils are called the "phase" wires, while the one connecting to their junction is the "neutral" wire. The pressure between a phase wire and the neutral is called the "star" pressure, while that between any two phase wires is called the "delta" pressure. This latter is 1.732 times as great as the star pressure. For greater safety in operation--principally to prevent abnormal rises in pressure between a phase wire and earth—the neutral wire is thoroughly "grounded" by being connected to a plate embedded in the moist earth.

The 50 volts pressure generated at Lauffen was "stepped up" by transformers of 8,000 volts, delta, at which pressure the current was transmitted.

DEVELOPMENT OF WATER POWERS.

After the success of polyphase transmission had been thus established, a great impetus was given to the development of water powers, and the following years found this system adopted by many companies. One of the first of these in America was built at Telluride, Colorado, in 1892. The original pressure used here was 3,000 volts, three-phase, straight from the generator. As a result of an extended series of experiments made on this line in 1896, much valuable data was obtained regarding high-tension transmission; and to-day there are many such systems, some operated at a pressure as high as 40,000 volts, which is the pressure now used at Telluride, while a few others are going still higher. The limit to-day seems to be about 60,000 volts, but even this may be increased as the art advances.

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*NOTE. A period is the fraction of a second for one complete cycle of the alternating wave.

The Sacramento-Folson line, in California, built in 1895, originally transmitted 1,000 H.P. at 11,000 volts, three-phase. The generators were wound to give a pressure of 800 volts, and this was raised in transformers to 11,000 volts.

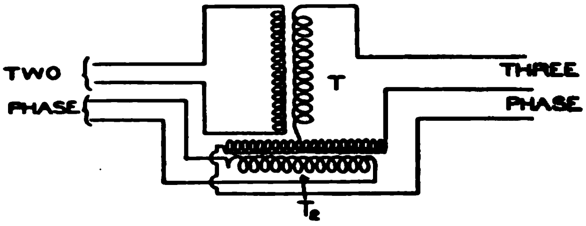


Fig. 11.

The Mechanicsville, N. Y., and the Snoqualmie Falls, Wash., plants are the most important three-phase transmission systems built in 1898. In the former, a transmission pressure of 12,000 volts, 38 cycles, was adopted; while in the latter, the generated pressure of 1,000 volts, 50 cycles, were stepped up to 25,000 volts.

Many of the polyphase stations built in the early nineties were equipped with two-phase generators. The two-phase currents were then stepped up and transformed to three-phase currents by means of a scheme of connections devised by Mr. Charles F. Scott. This connection is shown in Fig. 11. In this diagram, T and T_2 are two transformers, the primaries of which have the same number of turns and are connected to the two phases of the two-phase circuit. The secondary of T has only .866 times the turns of the secondary of T_2. By connecting one end of the secondary of T to the middle of the secondary of T_2, as shown, three-phase currents of equal pressures on each phase are obtained from these secondaries.

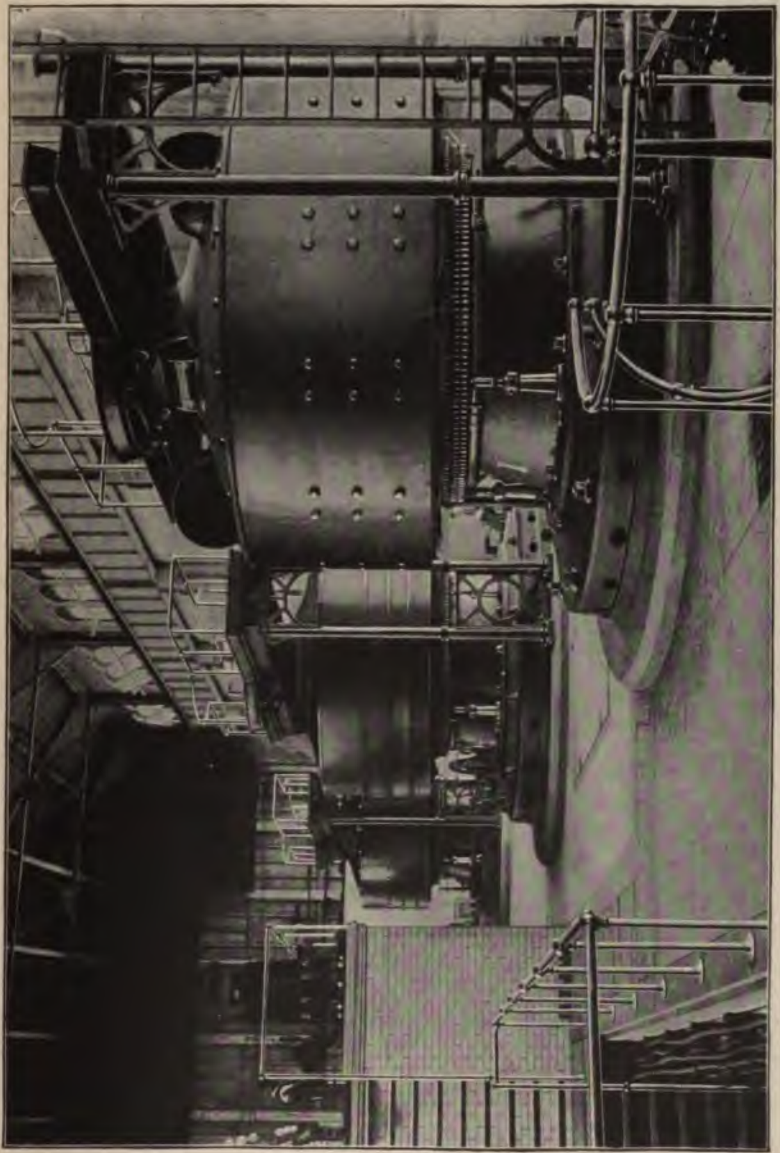


Fig. 12 Interior of Power House No. 1, at Niagara.

The best known example of this is the system at Niagara Falls, N. Y., where 25-cycle two-phase currents, generated at 2,200 volts, are transformed to three-phase currents at 22,000 volts, at which pressure the energy is transmitted to Tonawanda and to Buffalo, the latter being about twenty miles from the station. When this station was first operated, in 1896, the transmission pressure was 11,000 volts. Since that day many high-tension transmissions have sprung into existence; and the increase in voltage is keeping step with the improvement in insulators, as already noted. An interior view of Power House No. 1 at Niagara Falls is shown in Fig. 12.

FUNCTION OF THE STORAGE BATTERY.

While these important developments in cross-country transmission were under way, the engineers of the urban stations also had a few problems to solve. The convenience and other desirable features of the use of electric light and power were now being widely appreciated, especially when the cost of the lamps was reduced; and electric motors also were being used more liberally, in sizes from one-fourth horsepower to 300 H.P. and larger. This meant a big increase in the load on the station, as well as in the size of the district to be served. How to meet this increase economically, required an intelligent study of the problems of current distribution. As already noted, the distance over which it is economical to transmit current at a low voltage is limited; and, when the area to be served exceeds this limit, recourse must be had to more stations or to a higher distribution pressure. A study of the load curve of an average central station in a large city (Fig. 13) shows that the feeders are carrying their heavy current for but a short time each day. During all the remainder of the day, then,

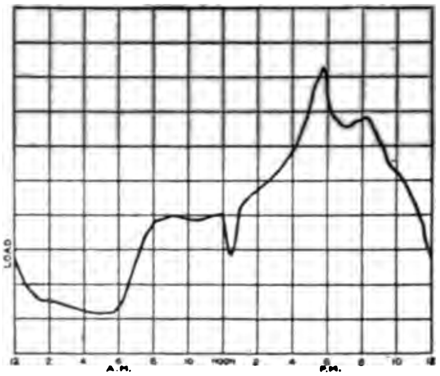
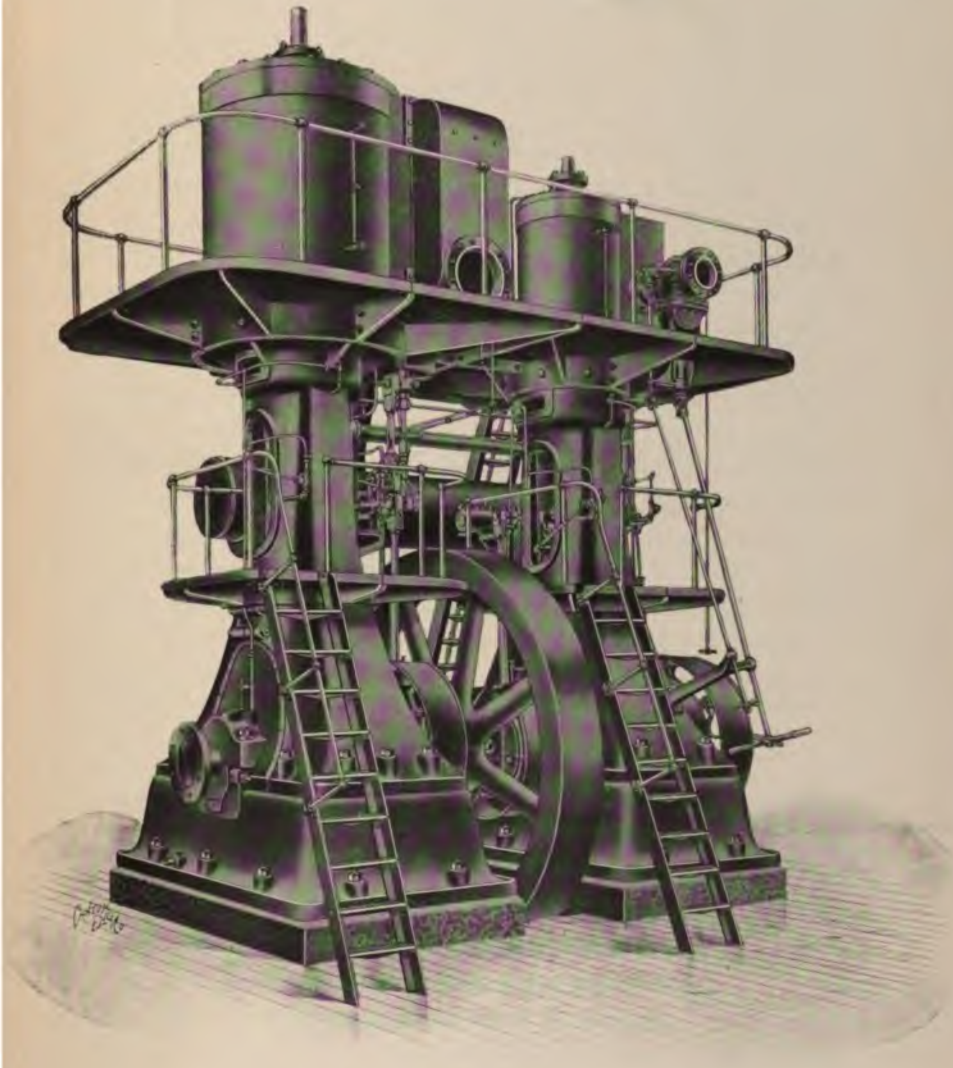


Fig. 13.



HEAVY-DUTY VERTICAL CROSS-COMPOUND ENGINE.

Buckeye Engine Company.

the current in these feeders is comparatively small; also, much of the generating capacity of the station is idle, representing just so much investment inactive and earning no returns. If now, during the period of light load, a current, additional to the regular load, can be sent over these feeders, and if this current can be stored in some way in a location within but near to the economical limit, so that it can be used at the period of heavy load, this storage substation will in turn become a point of distribution from which current can be sent out as far again as the economical limit. Here is where the storage battery filled the want. In 1894 we find storage-battery substations installed in Boston and New York, and soon after companies in other cities adopted them. In Boston, a number of battery substations were installed in the nearer outlying districts, all of them being connected with one another and with the steam station. The batteries are charged during the hours of light load by means of boosters, which form part of the substation equipment. Their usefulness, however, is not by any means limited to outlying districts. As an auxiliary to a generating station, it is considered good practice from the standpoint of economy to install a storage battery if the peak of the load does not exceed two and one-half hours. As a safeguard against interruption of service, and as a help in maintaining a uniform pressure on the system, they have been found almost invaluable.

CONSOLIDATION OF PLANTS.

The next step in the development was one of consolidation. Many cities had been liberal in granting franchises to lighting companies, and as a result there were built within the same city many systems of various excellence and stability. To the engineers of the consolidated company was then presented the problem of unifying the systems; but the changes to the new system had to be made without sacrificing the value of the investment represented by the generating apparatus and lines of the existing stations. Such a change, naturally, was made step by step, and thus required several years. In addition to providing for the existing load, the new system had to be designed for the future, and the probable development in the line of various classes of electrical apparatus had to be considered.

In our larger American cities, the load conditions can be divided into two general classes—one, in which a large load is concentrated over a comparatively limited area, which is the downtown or business district; and the other, the residence district, where the load is widely scattered over a large area. In the downtown district, nearly 30 per cent of the load goes to power users; therefore the system had to be adapted to all classes of motor service, as well as for lighting. For this service in such a district, the Edison direct-current three-wire system is certainly the most satisfactory, and this system has been pretty generally adopted. It permits the use of storage batteries; requires less copper than does the alternating-current system, because in it there is no loss due to inductance; gives better regulation; and is far better for general all-around power service.

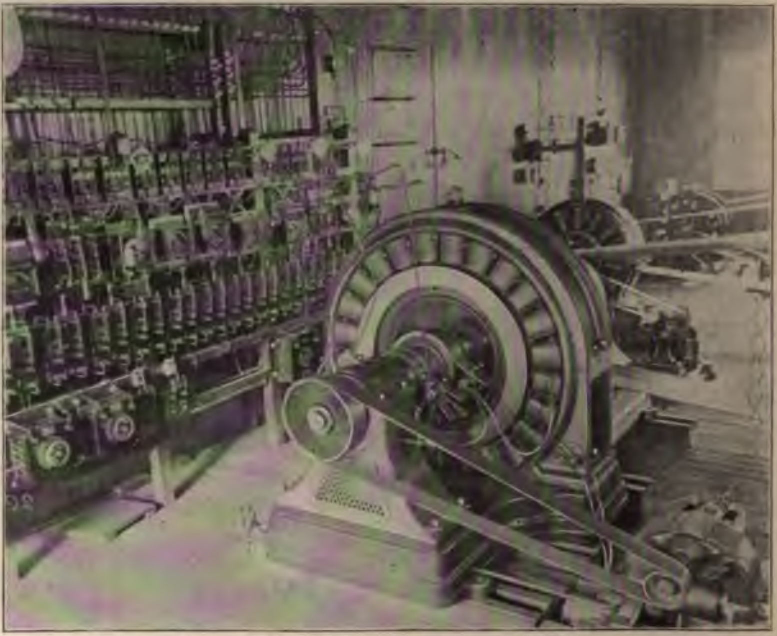


Fig. 14. Early Alternating-Current Station.

To consolidate several systems of this class was a simple matter. It required merely that the separate networks of mains be tied together, and a uniform pressure kept on the system by each station feeding into it. In the outlying districts, however, the problem was more complicated. Because of the scattered load, most of the systems feeding these districts used alternating current. But there was a wide divergence in regard to frequency and voltage. Some of the lines were 1,000-volt; others, 2,000-volt. Some used a frequency of 125 cycles; others, 133 or even 144 cycles. The secondary pressure ranged from 104 to 125 volts, while some of the earlier systems still maintained a secondary pressure of 50 volts. A few of the later stations had 2,000-volt lines, with a frequency of 60 cycles; and there were also polyphase (generally two-phase) lines for serving a motor load. A view of an early alternating-current station is given in Fig. 14.

High-Voltage Polyphase Systems. This conglomerate mass, then, had to be unified. A careful study of various systems showed the four-wire three-phase system, with a frequency of 50 to 60 cycles, to be the best suited to the distribution of such a load; and this system is being freely adopted. Good examples of it are found in Chicago, Milwaukee, St. Paul, and Cincinnati. The generator for this system is star-wound, with the neutral grounded, as already explained. The voltage at which this system is generally operated is 4,000 between phase wires. This gives a pressure of approximately 2,300 volts between any phase wire and the neutral; and the single-phase lighting feeders are switched on to this 2,300-volt

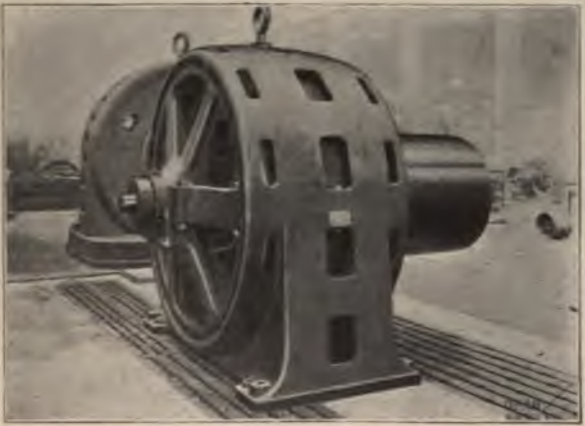


Fig. 15. Polyphase Induction Motor.

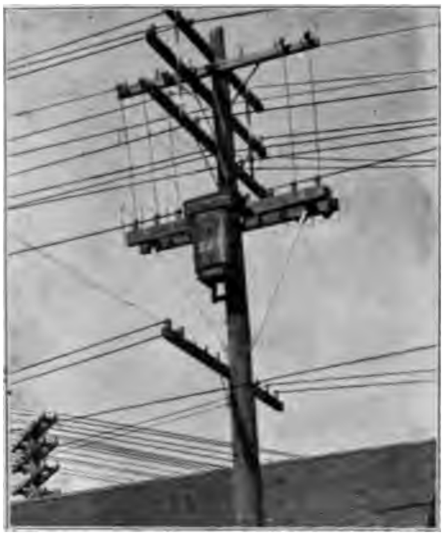


Fig. 16.

connection. The various feeders are connected each to one of the phases and the neutral, so that the three phases are approximately balanced. For a power load, then, connection is made to all three phases, and the motor is usually of the polyphase induction type, of which one is shown in Fig. 15. Where the capacity of the motor is very small—under 3 H.P.—the single-phase type of induction motor, equipped with some special starting device, is often used. Step-down of the voltage to the service pressure is, of course, accomplished by means of the ordinary 2,300-volt static transformers.

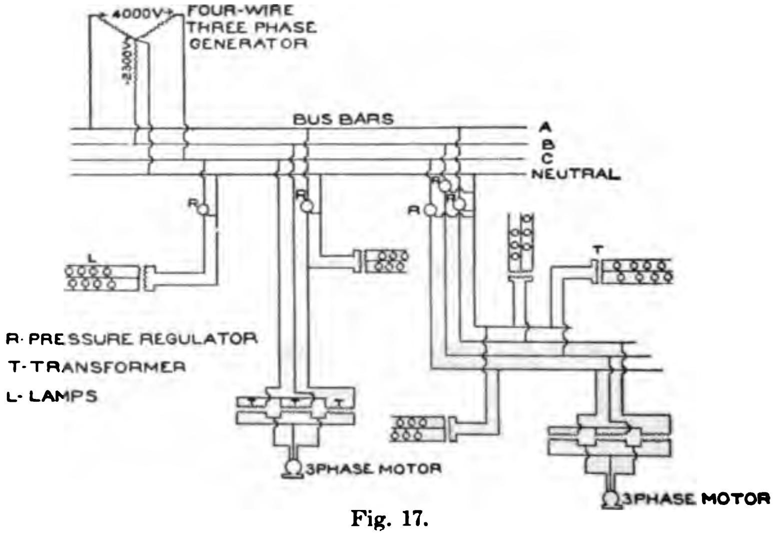


Fig. 17.

In Fig. 16 is seen a 150-light (7.5-K.W.) transformer on a pole. The two wires coming down at the right are the 2,300-volt primaries; while the three-wire secondaries, of 115 volts per side, are brought up at the left. A diagram of a four-wire three-phase distribution is shown in Fig. 17; and in Fig. 18 is seen a switchboard installed for such a system.

When the transmission distance is great, this three-phase pressure can be raised to any desired amount, and then stepped down again at the substation, the local distribution again being done on 2,300-volt single-phase feeders with a pressure of 4,000 volts between phase wires. In some cities, a two-phase system was adopted; while others, again, used the three-wire three-phase system (in which a neutral conductor is not used and all load is connected between phase wires). Brooklyn has a two-phase 2,300-volt 60-cycle system in the residence section; Philadelphia also, though in the latter city the current is generated at 5,500 volts and stepped down to 2,300 volts alternating-current distribution.

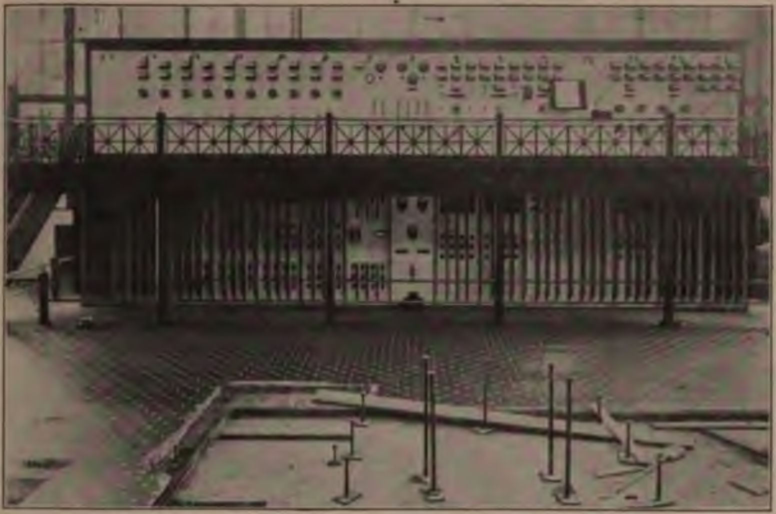


Fig. 18. Switchboard of 4-Wire 3-Phase Distribution System.

A 500-volt two-phase generator is shown in Fig. 19. For higher voltages the revolving-field type is used, thus avoiding collector rings and brushes for the high-voltage current. At the South Boston station of the Boston Electric Light Company (now part of the Boston Edison Illuminating Company), the generators are wound for 2,300-volt three-phase 60-cycle currents.

In the direct-current districts, the load often increased very heavily in sections somewhat remote from the generating or the distributing center; and then it became a question of more stations, more copper, or some other additional means of transmission. To provide enough copper for satisfactory transmission and regulation, would bankrupt a company. To build and operate a new generating station in each section of heavy load, would be equally ruinous. Consequently recourse is had to other means of transmission. The success and the comparative copper economy of polyphase transmission lines, already mentioned, showed that system to be the proper one to adopt; and the three-phase system was chosen as the means to transmit current to substations located at or near the electrical center of the load. Such a transmission system, from a large alternating-current station in preference to several direct-current generating stations, is considered good engineering whenever the total energy generated is large as compared with that used at any one locality. The voltage determined upon depended to some extent on the local conditions, but more largely on the efficacy of the insulation of underground cables, since in the cities all lines must be below the surface. In the early days of underground cables, 5,000 volts was thought very high pressure; to-day 25,000 volts is not considered excessive; and a recent article in the *Electrical Age* stated that an underground cable system will soon be installed, to be operated at 30,000 volts. The insulating material used in these high-tension cables consists of paper treated with a resinous compound, the thickness in the 30,000-volt cable

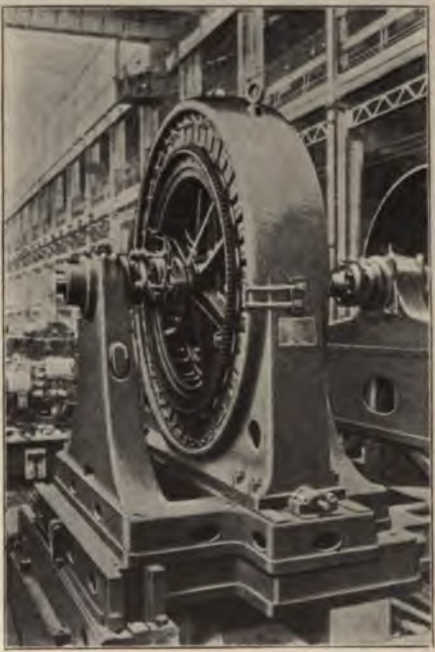


Fig. 19. 500-Volt 2-Phase Generator.

being about one-half inch. Over this is a lead sheath about $\frac{1}{8}$-inch thick, to protect the cable against moisture and mechanical injury. These cables are drawn into ducts laid below the surface in the streets, as shown in Fig. 2.

One of the earliest instances of the use of a three-phase transmission to a substation, for conversion to direct current of an Edison system, was in Chicago, where, in 1897, a 250-K.W. inverse rotary converter, which converted direct current of 250 volts to three-phase 25-cycle currents was installed at the Harrison Street station. By means of step-up transformers, this pressure was raised to 4,500 volts, the pressure of the transmission. In the substation on Wabash Avenue, near Twenty-seventh Street, this voltage was stepped down again; and, after passing through the rotary converters, the current was fed into the direct-current system at 115 volts, one rotary being connected to each side of the Edison system. Such was the humble beginning of the very extensive system of high-tension transmission lines and substations, which, at double the initial voltage of 4,500, is now in operation in Chicago.

In the same year there was installed in Brooklyn, N. Y., a similar transmission system with a rotary converter substation. Here the current was generated at 6,600 volts, 25 cycles, three-phase, at the Union station, a similar system to that operated by the New York Edison Company. In the magnificent Waterside station of this latter company, there are at present eleven 5,500-H.P. vertical engines, each driving a 4,500-K.W. three-phase 25-cycle 6,600-volt alternator. A 5,000-K.W. Curtis turbo-generator is being installed, and there is room for four more. This will make a total rated capacity of 75,000 K.W., all power being generated as alternating current for transmission to rotary converter substations, from which it will feed into the Edison three-wire direct-current system. In the splendid new Fisk Street station in Chicago, 9,000-volt 25-cycle three-phase current only is generated, all by Curtis turbo-generators. Fig. 20 shows a Westinghouse-Parsons unit of 5,000 K.W. capacity.

In Philadelphia, the 5,500-volt two-phase 60-cycle system, already referred to, is used for transmission to rotary converter substations, as well as for the alternating-current distribution, Fig. 21 shows a row of rotary converters of a substation located in

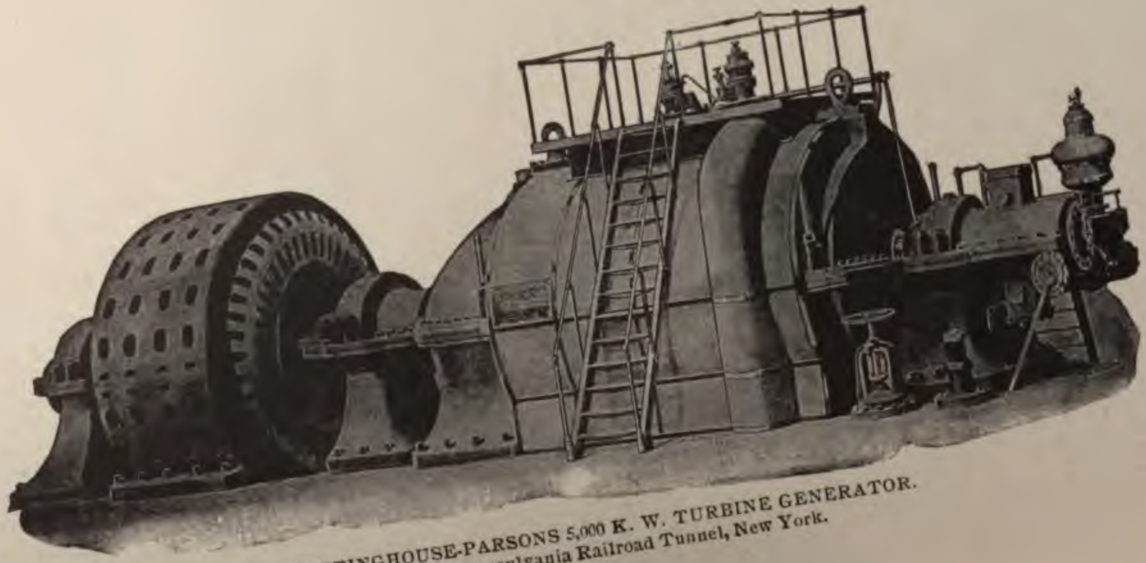


Fig. 20. WESTINGHOUSE-PARSONS 5,000 K. W. TURBINE GENERATOR.
For the Pennsylvania Railroad Tunnel, New York.

the basement of a sky-scraper in the heart of the business district of Chicago.

Where the load connected to transmission lines consists solely of substation converting apparatus, a low frequency is desirable because of the accompanying low inductive and capacity reactance of the lines, and also because of the slower speed of the synchronous motors and rotary converters which is had for a given number of field poles with a lower frequency. The higher the frequency, the greater the number of poles required, or the greater the speed. Because of the necessary number of commutator bars required between the brushes of a D. C. machine, and therefore also on a rotary converter, the distance between the centers of the pole pieces (that is, the pole "pitch") cannot be less than a certain fixed limit; and, therefore, for a given speed, the lower frequency allows a far simpler and cheaper construction. The higher-frequency machines are also more liable to "hunt" especially when the load varies considerably. Furthermore, double-current generators having a commutator connected to the armature windings for direct current, and also having connections to collector rings from which alternating current is taken off, are not practicable for frequencies much above 25 cycles. These double current generators, producing both direct and alternating current at the same time, form a very valu-

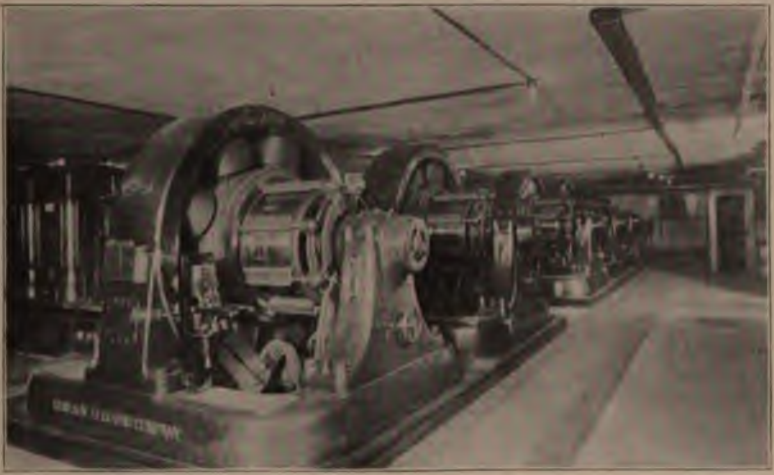


Fig. 21. Rotary Converters in Basement of Office Building.

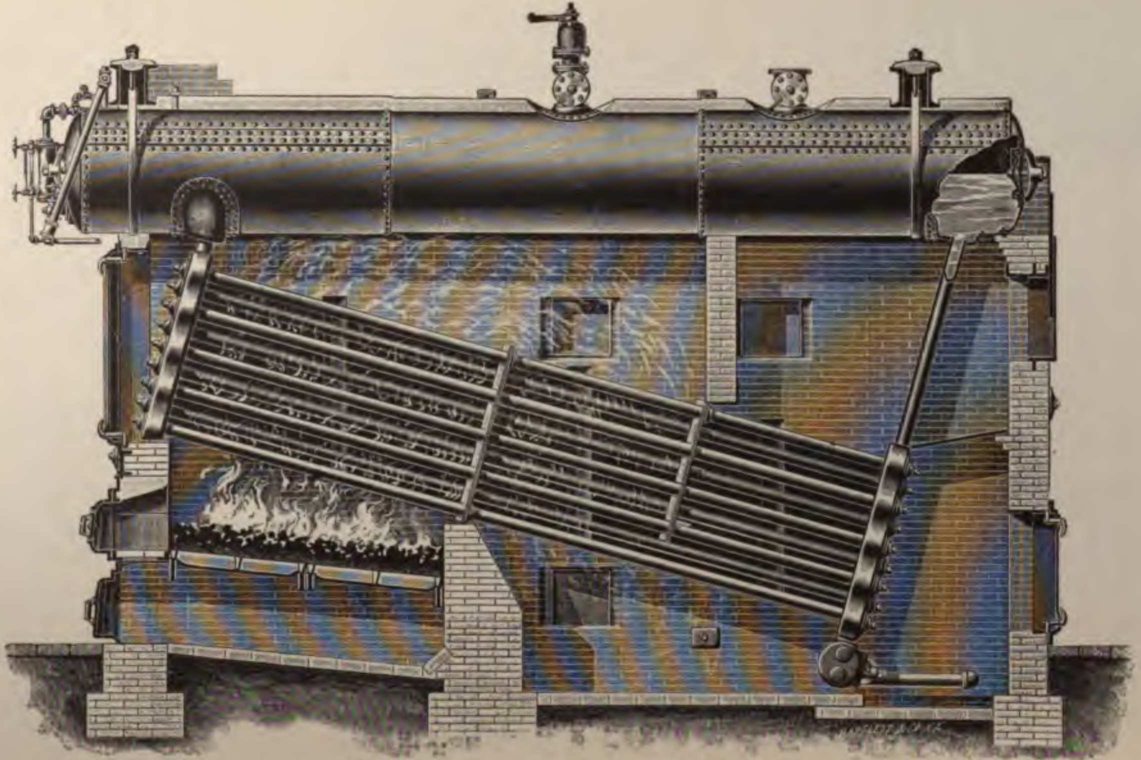
[illegible]

[illegible] in a large station in which both these currents are generated, the direct current for general distribution, and the alternating current for transmission to substations. A frequency of 25 cycles is therefore generally accepted as the most desirable for straight transmission; but the alternations are noticeable on incandescent lamps at even 30 cycles, while arc lamps will not burn at all satisfactorily on frequencies of less than 40 cycles. Because of these facts, the alternating distribution, as distinguished from transmission to substations, is effected by 60-cycle current. The 25-cycle transmission current is then converted to current of 60 cycles per second by means of motor generators or straight frequency-changer sets.

In Europe, a compromise frequency of 42 and sometimes 50 cycles is common; and current is transmitted and distributed at this frequency, thus requiring only voltage transformers and no frequency changers. A few 25-cycle systems have been installed in Germany. For converting to direct current, motor generators are used more freely than are rotary converters. European transmission lines of 10,000 volts three-phase are not uncommon.

With the advent of polyphase transmission in connection with lighting and power systems, the old 500-volt power lines are gradually being abandoned, the power load being connected to the 230-volt circuit of the Edison three-wire system, or, if in the outlying districts, to the polyphase 60-cycle lines. Series arcs have already been largely displaced by constant-potential arc lamps. What this new system meant to the neighborhood in which the old stations were located, will be appreciated when one remembers the noise and dirt and smoke of these old stations, and then views Fig. 22, a substation set in the rear of a lot in a fine residence section.

We have seen, then, how the high-voltage polyphase system has been evolved out of, and has unified, the mixed systems which were brought under one head during the era of consolidation. A study of some of the newest installations leads to the thought that perfection of system has almost been reached, and that further progress will be rather along the line of higher efficiency of apparatus at both ends of the system. When the true electrical era has arrived, when houses no longer have need of chimneys and all operations are performed electrically, then new problems will arise. How they will be met, none can now say; but they will be met successfully. Another Edison—many of them, perhaps—will arise; and then our splendid systems of to-day may ultimately be supplanted by one of which the most imaginative dreamer as yet has seen no vision.



BABCOCK AND WILCOX WATER-TUBE BOILER.

A GRAPHICAL METHOD OF RECORDING DATA OF BOILER TRIALS.

The usual method of keeping the data of a boiler or engine trial is to tabulate the readings. From these readings the results—which are also tabulated—are calculated. To the engineer in charge of the test, these figures are partially satisfactory, but for anyone else to get a good idea of their meaning, careful study is necessary. The tabulated figures give little information regarding the uniformity of conditions during the trial.

To represent the readings and conditions so that anyone interested in the subject can know them at a glance, a graphical record may be made on co-ordinate paper. This chart has so many advantages that it is well worth the little trouble. For the benefit of those not familiar with graphical representations on co-ordinate paper, a brief description is here given.

LAYING OUT THE CURVES.

The first thing to do is to find out the limits between which the readings are likely to vary. For instance, the steam pressure under working conditions will probably vary not more than ten or fifteen pounds. The engineer in charge of the plant usually knows the limits of feed-water temperature. After noting the variations of all the items, the limits may be laid off on the edge of the ruled paper.

The scale to which the readings are plotted depends upon the item. It is quite evident that the feed-water temperature curve should be plotted to a *larger* scale than the curve of flue temperatures. A little thought and calculation will easily settle these points.

As an example, let us consider the accompanying table and Fig. 1. The table shows the readings taken during a certain boiler test recently, and the curves of Fig. 1 form the graphical record of the readings. The readings are given up to 3 o'clock only, as these are sufficient to show the method.

Of course, the layout varies with each test and the scales may be chosen to suit conditions. In Fig. 1, each small division (vertical) represents the following increments:

ire of flue gas	20°	
Ter ire of feed water	5°	
St ssure	2	pounds
Dr ies of water)	.05	inch
Calo r (quality of steam)	.01	
Wat	20	cub. ft.
Coa	200	pounds

Tim plotted along the horizontal as shown. It will be ed that all the readings except those of the amounts of coal e taken at half-hour intervals.

LOG OF TEST.

IME	COAL		WATER METER	TEMPERATURES		STEAM PRES-SURE	DRAFT	QUALITY OF STEAM
				FEED	FLUE			
.00			226	136	460	86	.47	.97
7.30	7.30	400	267	139	496	91	.49	.98
8.00	8.05	400	304	144	500	91	.50	.97
8.30	8.55	400	337	141	514	92	.52	.965
9.00			379	140	520	93	.52	.97
30	9.40	600	422	134	522	91	.51	.99
00	10.15	400	491	130	520	91	.52	.98
.30			534	130	510	90	.53	.97
.00	10.50	400	564	133	518	91	.52	.98
11.30	11.25	200	610	140	520	92	.54	.98
12.00	12.00	400	640	142	480	91	.53	.98
12.30			650	140	470	90	.48	.98
1.00	1.05	600	672	142	496	86	.50	.99
1.30	1.30	400	723	136	510	90	.53	.99
2.00	2.15	400	763	150	520	91	.54	.98
2.30	2.35	400	810	152	536	93	.53	.98
3.00			850	150	536	91	.52	.98

After determining the starting-points, it is an easy matter to plot the curves. Let us take the flue temperature as an illustration. From 7 o'clock to 8 o'clock, the temperature rises 40 degrees (500 – 460 = 40), and as one division equals 20 degrees (see table above), the curve rises two divisions as shown. At 9 o'clock the reading is 520 degrees, hence the curve rises one division. By remembering the scales, each reading may be plotted as soon as taken. It is usually easier to plot the increase or decrease from the last reading; but if this is done, the plotted points should be verified occasionally by referring to the base-line of the curve in question.

PLOTTING THE CURVES.

For plotting the curves, the co-ordinate paper may be tacked on a board and kept in some convenient place so that each observer may plot his readings immediately after taking them. This is advantageous in that each observer need remember only his own scale and plot his own curve; but it may cause confusion, especially if there are many observers. If there is a sufficient number of observers, one may have charge of the plotting and either go around and get the observations, or the readings may be brought to him to plot and record as a duplicate table.

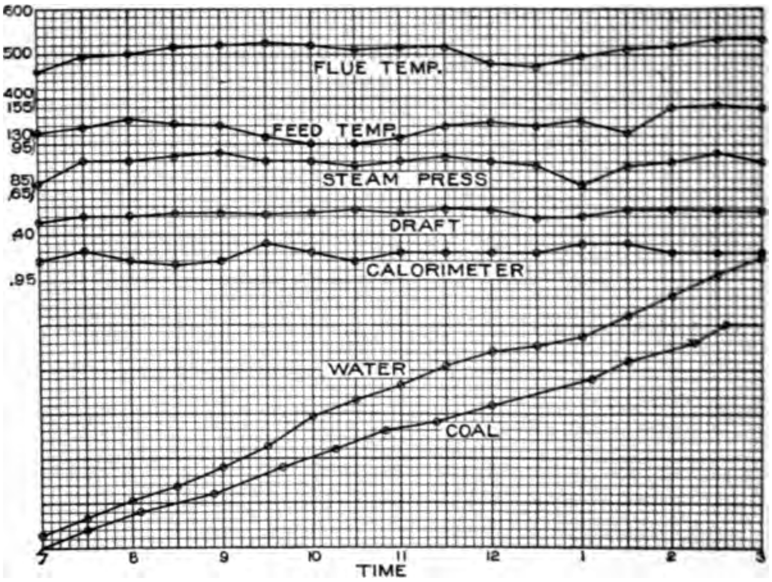


Fig. 1.

The reading and plotting of pressures and temperatures will present no difficulty, because they can be taken at stated intervals and the variation is slight. The coal and water, however, are not so easily taken care of. In the case of hand-firing, the coal may be weighed and supplied to the floor in front of the boiler in 200-pound lots. Or, all the coal for the test (as nearly as it is possible to estimate it) may be weighed at the start. If the readings are to be plotted, it is well to supply the coal in 200-pound lots as needed. If the amount of coal kept in front of the furnaces is very slight, that is, if the 200-pound lots are recorded only at the time of firing, the curve showing the amount of coal used will be quite satisfactory.

'e s the item of coal consumed cannot be recorded nter As the squared paper (see Fig. 1) allows per ho ach space is the equivalent of six minutes; emember g this scale, the time can be plotted very Thus, in ig. 1, the first lot of coal was fired at 7.30, d at 8.05, the third at 8.55, the fourth at 9.40, and so on. h mechanical stoking, the curve of coal consumption e plotted in this way, because the hoppers are filled when- ssary and the amount of coal used between any two inter- time must be estimated. This estimate would be so le that it would be worthless.

overcome this a speed counter may be attached to the feed m, and the readings taken at the given intervals. When is over, the amount of coal used per 100 revolutions of the ounter is easily found, since the total amount of coal con- s known, and the number of revolutions is known. In y a curve may be plotted to show the coal consumption; it probably be as accurate as for hand-firing.

The water fed to the boiler may be measured by a meter, in , in barrels, or by any other convenient method. In Fig. 1, amounts are in cubic feet as given by the meter. These readings may be plotted as they are, or they may be reduced to pounds by multiplying by a factor which varies with the temperature. This factor will approximate 62.4. If a water meter is used, it should be carefully calibrated so that the error in this item may be reduced to a minimum.

In plotting the coal and water, it would be well to reduce the meter readings to pounds, and then plot both coal and water to the same scale. This, however, is not at all necessary.

It is a well-known fact that many short boiler tests show remarkable results as to evaporative efficiency. The excellence of these results is due largely to an incorrect estimation of the amount of fuel on the gates when starting and stopping. In making a test from a flying start, the conditions of the fires is carefully noted at the time the first readings are recorded. This usually occurs just after cleaning or a few minutes after cleaning.

To eliminate these starting and stopping errors, the graphical method will be found of great assistance. To do this, the

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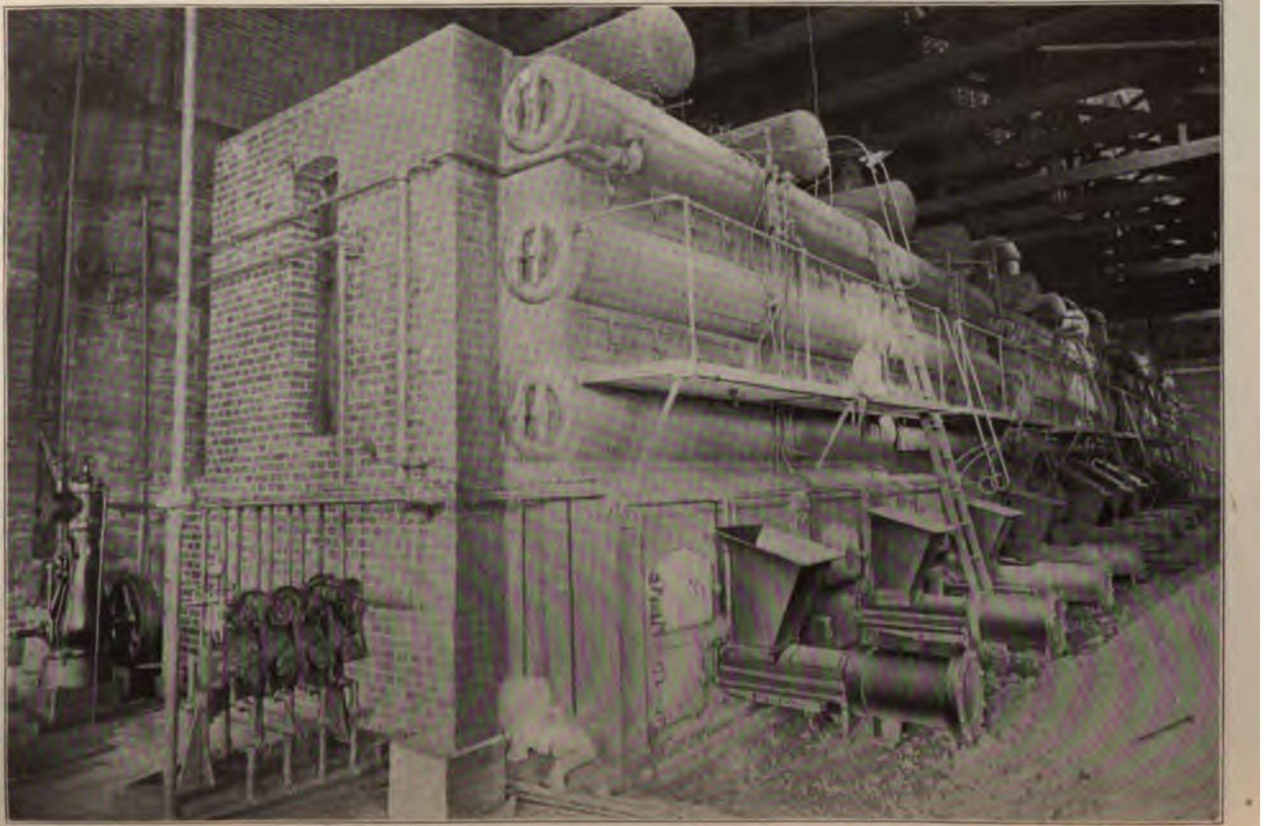

JONES UNDERFEED STOKERS IN STATION OF THE TOKYO ELECTRIC
TOKYO JAPAN

curves should be plotted carefully and then the two ends cut out. As the water level is usually marked at the beginning of the test, careful note should be made at each reading, so that, if the water is above or below normal, the amount be allowed for.

The curves shown in Fig. 1, are constructed by connecting the points by straight lines. Some prefer to draw a smooth curve through these points.

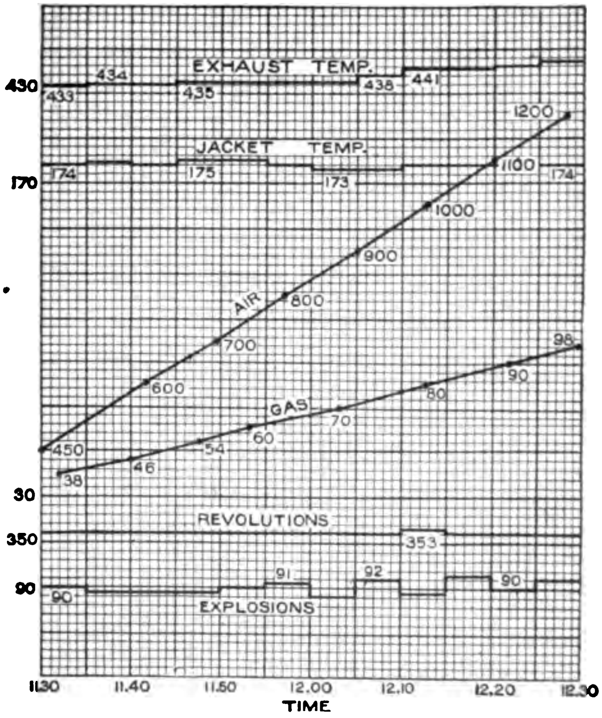

Fig. 2.

The graphical method shows inaccuracies in readings, such as counting a lot of coal twice or reading the meter incorrectly. While this is especially true of a test made while running under a steady load, the graphical log is valuable also if the load fluctuates, for the curves for coal and water should show the same relative positions to each other.

Fig. 2 is the graphical log from a test of a small gas engine. It serves to show the application of the same principle to a differ-

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lition to the curves shown, the curves for gas used orse-power per hour may be plotted if there are ers to measure the cards.

cal method is equally valuable in tests of engines inery. With necessary modifications it may be ng electrical machinery.

REVIEW QUESTIONS.

PRACTICAL TEST QUESTIONS.

In the foregoing sections of this Cyclopedia numerous illustrative examples are worked out in detail in order to show the application of the various methods and principles. Accompanying these are examples for practice which will aid the reader in fixing the principles in mind.

In the following pages are given a large number of test questions and problems which afford a valuable means of testing the reader's knowledge of the subjects treated. They will be found excellent practice for those preparing for College, Civil Service, or Engineer's License. In some cases numerical answers are given as a further aid in this work.

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC LIGHTING.

1. State the current, voltage, candle-power, and efficiency of the incandescent lamp most commonly used.

2. What do you understand by the "smashing point"?

3. Give the main points of difference between the three forms of arc lamp mechanism.

4. Mention the three principal parts of the Nernst lamp.

5. Describe with sketch the anti-parallel system of feeding.

6. Prove the law that illumination varies inversely with the distance.

7. Why is arc light photometry a more difficult problem than incandescent?

8. Calculate the illumination three feet above the floor at the center of a room 18 feet square and 12 feet high, lighted by four 10-candle-power lamps 9 feet above the floor at the center of the side walls, assuming the coefficient of reflection to be 50%.

9. What material is used for the filament of incandescent lamps? Explain why.

10. From the curve given in Fig. 4, determine the efficiency which corresponds to the temperature of 1300° Centigrade.

11. What is the object of double carbons in an arc lamp?

12. What is meant by mean spherical candle-power?

13. What is the function of the heater in the Nernst lamp?

14. Describe the Bunsen Photometer.

15. How does the lighting of public halls differ from that of residences?

16. Why cannot platinum wire be used for the filament of incandescent lamps?

17. In a direct-current arc lamp, which carbon burns away the more rapidly?

18. How are arc lamps rated?

19. What are the important advantages of the two-wire parallel system of distribution?

20. Name and describe the most desirable standard for photometric measurements.

21. How many measurements should be taken in the determination of spherical intensity?

22. What is meant by flashing? Explain.

23. Define emissivity.

24. If the voltage of an incandescent lamp be increased 4% above normal, what is the effect on the candle-power, efficiency and light?

25. Explain the Cooper-Hewitt lamp, stating the two methods of starting.

26. Compare the open and enclosed arc lamps.

27. Why is the positive carbon placed above the negative in a direct-current arc lamp?

28. Sketch and name the different forms of incandescent lamp filaments.

29. Under what conditions can a 3.1-watt incandescent lamp be used?

30. What is the function of the arc lamp mechanism?

31. What are the advantages of the three-wire system?

32. Why is it necessary to exhaust the bulb of an incandescent lamp?

33. At what point in their life should incandescent lamps be replaced?

34. What is the object of a resistance in series with the arc lamp in constant-potential direct-current systems?

35. Name the advantages of the Nernst lamp.

36. What sort of lamps and of what candle-power should be used in residence lighting?

37. Give the characteristics of the Cooper-Hewitt lamp.

38. What will be the external resistance on a 110 volt constant-potential system, if the load consists of 437 lamps of 16 candle-power?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC RAILWAYS

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1. (a) Upon what does the heat developed in an electric heater depend? (b) Explain the method of obtaining different degrees of heat in the electric car. (c) How much power in K. W. is consumed in heating a car, if the heaters take 6 amperes and the cars run on a 500-volt circuit?

2. (a) State briefly the essential requisites for a first-class car motor. (b) Describe one form of motor suspension.

3. What is the speed in revolutions per minute of the motor armature of a car going at the rate of 8 miles per hour? Diameter of car wheel = 33 inches, single reduction gear, 14 teeth on the pinion, 72 on the axle gear.

4. Explain the series-parallel method of controlling the speed of a car, and the method of gradually increasing the speed of a car by the General Electric "K" type controller.

5. Give the principle of a good form of electric brake.

6. Draw a diagram showing the course of the current in the return circuit when the rail is paralleled by a large water main. Denote the points at which the strongest electrolytic action will take place on the pipe assuming the trolley positive.

7. What are the advantages of the third-rail system?

8. What are the most important factors to be considered in locating a power house for a given system?

9. How may the alternating current be applied to electric-railway work, direct-current motors being used on the cars?

10. (a) How is the electrical circuit maintained at switches and crossings in the third-rail system? (b) How is the car enabled to cross such places?

11. Give the principle of the automatic circuit-breaker.

12. Why is it necessary to bond the rails?

13. Explain how and for what purpose storage batteries can be used in railway power plants.

14. Why is it necessary to use feeders on long lines?

15. Explain why pipes in the vicinity of the power house should be connected electrically to the negative terminal of the generator when the trolley is positive.

16. What is meant by the "Multiple Unit Control" system?

17. In the K controller how is arcing prevented between the contract rings and fingers, when the circuit is broken?

18. What forms of resistance are commonly used in electric-railway work?

19. What is the "dead man's handle?"

20. How is the current collected from the third rail in the third-rail system?

21. Describe briefly the conduit system. In what cities is it used?

22. Describe with sketch the connections of generators and feeders in a power station for direct-current railway work.

23. Do you believe that alternating-current motors will ever come into extensive use for electric railway work? Give reasons.

24. If a car fails to start, to what causes might this be due?

25. What is the canopy switch and in what way is the car circuit-breaker superior to it?

26. Why is it that expansion and contraction do not absolutely forbid the use of a welded joint in a street-railway rail?

27. Describe a method of bond testing.

28. Explain the transformer test for short-circuited armature coils.

29. Explain the action of the air brake.

30. What are the advantages of the high tension system of distribution?

31. Which is used more frequently the Westinghouse automatic air brake, or the straight air brake in electric-railway work?

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

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1. Why is the steam turbine well adapted for direct connection?

2. On a three-wire system is it better to use 110-volt or 220-volt motors? Explain why.

3. Describe construction and operation of the Fort Wayne self-starting synchronous motor.

4. What methods are used for controlling the speed of induction motors? Which one is preferable?

5. How can the friction of brushes and bearings be tested roughly?

6. What points should be considered in the selection of a machine?

7. Give a sketch of the connections of a compound-wound motor.

8. What is the advantage of a synchronous motor when its field is over excited? Explain.

9. Give a safe rule to follow for personal protection when handling electrical circuits of a sufficiently high voltage to be dangerous.

10. What precautions must be taken in fixing a direct-connected set?

11. Why should starting boxes always be furnished with direct-current motors?

12. (a) How are small induction motors started? (b) Why cannot large sizes be started in the same way?

13. If a machine is to be taken apart for the purpose of cleaning or inspecting it, what precautions should be taken?

14. Describe the method of lacing a belt.

15. How are dynamotors and motor-generator sets started?

16. What precaution should be taken when starting a new machine for the first time.

17. Immediately after stopping a machine what should be done to it?

18. What advantages have circuit breakers over fuses?

19. What are the objections to series motor for single-phase circuits?

20. What is an enclosed fuse, and in what way is it better than a link fuse?

21. Give a sketch of the wiring for a three-phase Y system for both light and power distribution.

22. Explain the principle and use of a starting compensator.

23. What advantage does rope driving possess over ordinary belting?

24. When synchronizing two alternators should the switch be closed when the two machines are approaching synchronism, or when they are receding from it.

25. How can sparking at the commutator be measured roughly?

26. In placing a knife switch should it be so located that gravity tends to open it or to close it?

27. Describe with sketch the connections for two compound-wound dynamos in parallel.

28. How would you test a machine for balance?

29. Describe with sketch the connections for a typical single-phase installation.

30. What points must be considered if two alternators are to be run in parallel?

31. Describe with sketch the method of synchronizing on a three-phase system.

32. Should the loose side of a belt be on the top or below? Explain why.

33. Give a sketch of two generators connected on the three-wire system.

34. Why is a series motor particularly adapted for railway work?

REVIEW QUESTIONS

ON THE SUBJECT OF

MANAGEMENT OF DYNAMO-ELECTRIC MACHINERY.

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1. In measuring resistance with the Wheatstone bridge, what is the objection of using a ratio of 1000 : 1 or 100 : 1?

2. Describe a tachometer. What advantage has this over the speed counter?

3. What is the torque of a 20 horse-power motor running at the rate of 600 r.p.m.?

4. When the armature of a machine becomes overheated and the belt is tight on the tension side, to what would you ascribe the cause and how would you remedy it?

5. Explain how to true up the commutator in case it becomes rough or uneven.

6. Describe a method of testing to see if the armature is centered between the pole pieces.

7. What is the pull in pounds in the case of a 40 horse-power motor if the speed is 550 r.p.m. and the pulley is 3 feet in diameter?

8. What do you understand to be meant by a ground in the armature?

9. If the speed of a generator is too high, what effect does this have on the voltage?

10. Describe with formula the direct-deflection method of measuring insulation resistance.

11. Describe a method of determining the current in a circuit if you have a voltmeter but no ammeter at hand.

12. How does eddy-current loss vary with the speed?

1 cribe the indicating wattmeter giving sketch of one connect ingle-phase mains.

14. w does an eccentric commutator manifest itself?

15. If the residual magnetism of a dynamo be weak or entirely destroyed, how would you explain the cause for the same? How would such trouble manifest itself, and what is the remedy?

16. What resistance does a Weston voltmeter usually have?

17. Supposing the commutator of a machine is covered with dark coating, while the commutator brushes and brush holders how marks of abnormal heat, what is likely to be the cause and hat remedy should be applied?

18. Name the causes of the voltage of a generator being too w.

19. What difficulty would arise in attempting to measure e armature resistance of a 20 horse-power 110-volt shunt machine ith the Wheatstone bridge?

20. In testing the output of a large generator, how would u dispose of the large current generated? Give two methods.

21. What is meant by the efficiency of a generator?

22. Which is preferable to use on a commutator, sand paper or emery?

23. Which is preferable, that the commutator should have a bright, clean appearance, or be covered with a brown glaze or polish?

24. How can Foucault currents in the pole pieces or field cores be detected? What usually gives rise to such action?

25. What is the advantage of over-compounding so that a machine gives a higher voltage at full load than at low load?

26. A motor which is running without load is found to take excessive current, give a cause and remedy for the same.

27. If the field coils of the machine are too hot as determined by testing with the hand, what remedy would you apply?

28. Why cannot insulation resistance be measured by means of the Wheatstone bridge?

29. How could you determine the speed of a belted machine without the use of any sort of a speed indicator?

30. What is meant by the efficiency of a motor?

31. How does hysteretic loss vary with the speed?

REVIEW QUESTIONS

ON THE SUBJECT OF

POWER STATIONS.

1. Why is it desirable to allow a reserve capacity when deciding upon the number of units to be installed?

2. Draw a diagram of the piping system for what you consider a first-class arrangement of the units.

3. Would you use a high or low-speed engine (*a*) in the case of a 200 K.W. generator; (*b*) in the case of a 300 K.W. generator; (*c*) in the case of a 1,000 K.W. generator?

4. When alternators are driven in parallel by gas engines, what arrangement is used to compensate for the variation in angular velocity?

5. Is it better to have a machine of very high efficiency at the expense of excessive cost, or to have it reasonable in price with lower efficiency?

6. What arrangement is now frequently used to avoid placing the different pieces of apparatus directly on the panels of a switchboard?

7. Explain the function of a substation and tell of what its equipment should consist.

8. What are the advantages of oil switches?

9. Explain why the capacity of a 6-phase rotary converter is greater than that of a single-phase, two-phase, or three-phase.

10. Which system of charging for power do you consider the fairest and best? Explain why.

11. Explain what is meant by a reverse-current relay, and give an example of its usefulness.

12. What factors must be taken into consideration when locating a rotary converter substation?

30. Why are the operating expenses of the hydraulic plant less than those of the steam plant?

31. If you were purchasing machines for a power station which was to supply both light and power, what frequency would you select, and why?

32. Is there any advantage in having the equalizer switch mounted on the pedestal near the machine instead of on the switchboard?

33. If in a central station there is not sufficient room to place both the boilers and engines on the ground floor, which piece of apparatus would you place on the second floor, and why?

34. Why should the power station be located as near as possible to the center of gravity of the system?

35. In the Curtis turbine what safeguard may be provided to prevent trouble in case the oil supply fails?